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Operation TEAPOT

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Project 3.6

EVALUATION OF EARTH COVER AS PROTECTION TO ABOVEGROUND STRUCTURES

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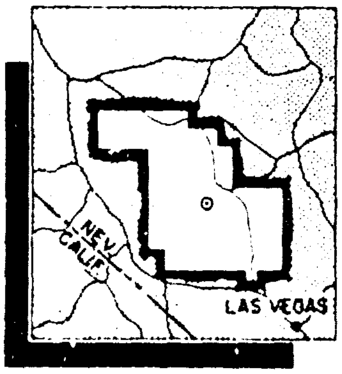

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OPERATION TEAPOT—— PROJECT 3.6

Report to the Test Director

EVALUATION OF EARTH COVER AS PROTECTION TO ABOVEGROUND STRUCTURES

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R. B. Vaile, Jr.
L. D. Mills, LTJG, USN

Bureau of Yards and Docks
Department of the Navy
Washington, D. C.

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DECEMBER 1956

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SUMMARY SHOT DATA

SHOT	CODE NAME	DATE	TIME *	AREA	TYPE	LATITUDE & LONGITUDE OF GROUND ZERO
1	Wasp	18 February	1200	T-7-4 1/	762' Air	37° 05' 11.6856" 116° 01' 18.7366"
2	Moth	22 February	0545	T-3	300' Tower	37° 02' 52.2654" 116° 01' 15.6967"
3	Tesla	1 March	0530	T-9b	300' Tower	37° 07' 31.5737" 116° 02' 51.0077"
4	Turk	7 March	0520	T-2	500' Tower	37° 08' 18.4944" 116° 07' 03.1679"
5	Hornet	12 March	0520	T-3a	300' Tower	37° 02' 25.4043" 116° 01' 31.3674"
6	Bee	22 March	0505	T-7-1a	500' Tower	37° 05' 41.3880" 116° 01' 25.5474"
7	ESS	23 March	1230	T-10a	67' Underground	37° 10' 06.1263" 116° 02' 37.7010"
8	Apple	29 March	0455	T-4	500' Tower	37° 05' 43.9200" 116° 06' 09.9040"
9	Wasp'	29 March	1000	T-7-4 2/	740' Air	37° 05' 11.6856" 116° 01' 18.7366"
10	HA	6 April	1000	T-5 3/	36620' MSL Air	37° 01' 43.3642" 116° 03' 28.2624"
11	Post	9 April	0430	T-9c	300' Tower	37° 07' 19.6965" 116° 02' 03.8860"
12	MET	15 April	1115	FF	400' Tower	36° 47' 52.6887" 115° 55' 44.1086"
13	Apple 2	5 May	0510	T-1	500' Tower	36° 03' 11.1095" 116° 06' 09.4937"
14	Zucchini	15 May	0500	T-7-1a	500' Tower	37° 05' 41.3880" 116° 01' 25.5474"

* APPROXIMATE LOCAL TIME - PST PRIOR TO 24 APRIL, PDT AFTER 24 APRIL
1/ ACTUAL GROUND ZERO 36' NORTH, 426' WEST OF T-7-4
2/ ACTUAL GROUND ZERO 94' NORTH, 62' WEST OF T-7-4
3/ ACTUAL GROUND ZERO 36' SOUTH, 397' WEST OF T-5

ABSTRACT

Earth-covered corrugated steel structures, both full-size and quarter-scale models, were tested on Shot 12 of Operation TEAPOT. The tests were designed to obtain a measure of the blast resistance and the radiation resistance of this type of structure (a 25-foot span arch) if it were used for a personnel shelter. A full-scale structure (originally constructed for Project 3.15 of Operation UPSHOT-KNOTHOLE and retested on TEAPOT) successfully withstood peak pressures of 11-psi side-on and 30-psi dynamic on the open plain. Another full-scale structure failed under the load produced by peak pressures of 30-psi side-on and 170-psi dynamic on the open plain. Prompt radiation was attenuated by a factor of 100; the radiation resistance would be greatly improved by additional thickness of earth cover at the crown.

The performance of the specific composite structure tested has now been adequately bracketed for military purposes and no further tests of it are recommended. Further tests of earth-covered corrugated steel-arch structures may be desirable if significant departures are made from the design tested on Operation TEAPOT.

The performance of the models was roughly consistent with expectations. Although further experimentation will be required before the reliability of the model results can be assured, the TEAPOT results suggest that static model tests prior to any further full-scale blast tests will enhance the value of the results, and will reduce the cost, of such full-scale operations.

FOREWORD

This is one of the reports presenting the results of the 47 projects participating in the Military Effects Tests Program of Operation TEAPOT, which included 14 test detonations.

For readers interested in other pertinent test information, reference is made to WT-1153, Summary Report of the Technical Director, Military Effects Program. This summary report includes the following information of possible general interest: (1) an overall description of each detonation, including yield, height of burst, ground zero location, time of detonation, ambient atmospheric conditions at detonation, etc., for the 14 shots; (2) discussion of all project results, a summary of each project including objectives and results, and a complete listing of all reports covering the Military Effects Tests Program.

ACKNOWLEDGMENTS

The successful planning, execution, and analysis of results of this test have been achieved through the extensive cooperation of many people and many organizations.

The radiation measurements reported here were taken by the Army Chemical and Radiation Laboratories and the Evans Signal Laboratory under Project 2.7 of Operation TEAPOT. Discussions with J. R. Hendrickson, E. H. Engquist, and J. P. Mitchell were particularly helpful.

The soil measurements, control of procedures, and placement of the earth cover were handled by Charles White of the Soil Mechanics Group of the Naval Civil Engineering Research and Evaluation Laboratory at Port Hueneme.

The measurement of air pressures against the earth berm by means of self-recording pressure gages was accomplished by the Ballistic Research Laboratories group under Julius Meszaros. This group also made a series of shock-tube measurements on a model of the structure, to assist in the planning of the field test.

The deflection measurements and airblast measurements using remote recording were accomplished by the Stanford Research Institute group headed by L. M. Swift under Operation TEAPOT Project 1.10.

The construction of the models was made considerably easier by the cooperation of the ARMCO Drainage and Metal Products, Inc. of Berkeley, California, who rolled both the steel- and the aluminum-arch sections at no charge.

The assistance of John Case, Structural Engineer, in both the planning of the tests and interpretation of the results and particularly in the design of the reinforcement of the door in the tunnel and of the end walls is acknowledged.

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Chapter 1
INTRODUCTION

1.1 OBJECTIVES

The primary objectives of Project 3.6 of Operation TEAPOT were to determine the degree of protection that earth cover offers to aboveground structures and, particularly, to test the adequacy of an adaptation of a corrugated steel-arch ammunition magazine, similar to UPSHOT-KNOTHOLE Building 3.15, as a personnel shelter. Both the blast resistance and the radiation resistance of such structures were objectives of the test. Because the structure tested on Operation UPSHOT-KNOTHOLE sustained no significant damage, it was an objective of the TEAPOT test to produce at least incipient collapse so that the capabilities of this design would be bracketed. The long-range objectives were to extend the knowledge of the benefits of earth cover in protecting aboveground structures and to obtain further insight into the mechanism of these benefits, toward the optimum design of aboveground shelters.

A further supplementary objective was to compare the performance of models with that of full-scale structures in order to permit more economical design of future tests.

1.2 BACKGROUND

Aboveground earth-covered structures were tested by the Navy on Operations GREENHOUSE and UPSHOT-KNOTHOLE. The new structure tested on Operation TEAPOT was similar to one of the two UPSHOT-KNOTHOLE structures (Project 3.15) which successfully withstood peak blast pressures of 11 psi side-on (Reference 1).

The TEAPOT test was designed on the basis that the weakest element in the final design of a shelter of this type is expected to be in the central section of the arch, where support from the end walls will be negligible. Since the building is weakest against forces transverse to its longitudinal axis, the building was so oriented that the side of the building faced ground zero. The test was designed with the philosophy that the central section of the arch was the primary element to be tested; the remaining elements, particularly the end walls, the tunnel entrance, and the door, were reinforced with the intent that their performance

would not interfere with the interpretation of the results of this test on the central span of the arch.

Analysis shows that a structure of this type (an arch) is very sensitive to the difference in load applied to the two sides of the building. Estimates of the aerodynamic situation led to the conclusion that increasing the dynamic pressure, from a value roughly estimated to have been 5 psi on UPSHOT-KNOTHOLE to a predicted value between 50 and 90 psi on TEAPOT, might increase this dissymmetry in loading to an even greater extent. Considering these factors and the results of the UPSHOT-KNOTHOLE test, a different shape of earth cover appeared to offer some advantages. On the new building, therefore, a different shape was used. The earth berm was widened and flattened to reduce the differential air-blast force against the two sides of the building and to strengthen the building beyond the strength of the one on UPSHOT-KNOTHOLE (U-K).

Building U-K 3.15 was located at a distance from TEAPOT Shot 12 where both the radiation and the blast load were expected to be in the range of interest, even though not as high as at the location of the main structure, Building 3.6. It was decided, therefore, to instrument Building U-K 3.15 within the limits of modest cost. To this end, the scratch gages used on UPSHOT-KNOTHOLE were rehabilitated and two sets of radiation-dosage measuring instruments were placed in Building U-K 3.15.

Models were added to this experiment with the primary objective of determining, if possible, the relationship between model and prototype performance. If this could be accomplished, considerable cost savings could be made in future tests. Six quarter-scale models were designed, three of steel and three of aluminum. The steel ones were designed with the intent that they should have the same ultimate strength as the prototype. That is, they should fail at the same value of peak pressure, both side-on and dynamic, and incidentally, their absolute deflection should be one quarter that of the prototype. The aluminum models were designed to have scaled deflections at yield. That is, the yield deflection of the model should be one-fourth the yield deflection of the prototype; and the air pressure load against the earth berm causing such deflection in the model should be one-fourth the air pressure causing such deflection in the prototype. (Coincidentally, the aluminum models would have scaled stresses under a scaled load.)

The models were located on the following basis (see Table 2.2). It was intended that the nearest of the steel models and the nearest of the aluminum models should sustain significant damage even if the actual blast pressure was the minimum felt to be reasonably probable. At the same time, the most distant steel and aluminum models were placed so that, even if the blast was the maximum felt to be probable, these models would be expected not to collapse. Finally, it was desirable to compare steel and aluminum models; hence the most distant steel model was placed at the same radius as the nearest aluminum model.

To assist in the planning of the field experiment, the Ballistic Research Laboratories (BRL) were asked to make a shock-tube study of a small model of the earth-covered structure. It was recognized that it would probably be impossible to simulate accurately in the shock tube the conditions expected in the field, particularly in regard to the high

value of dynamic pressure expected. In compliance with this request BRL made a shock-tube study involving measurements at nine gage positions for shock overpressures of 10, 20, 30, and 35 psi. The shock-tube results were self-consistent and satisfactory in every way except that, as mentioned above, it was not possible to attain sufficiently high values of overpressure. The results of these shock-tube measurements are discussed further in Section 5.4.

Chapter 2

STRUCTURES AND INSTRUMENTATION

2.1 BUILDING 3.6

The main structure (Building 3.6) was a 25-by-48-foot steel-arch ammunition shelter manufactured by ARMCO Drainage and Metal Products, Inc. This structure is shown in Figure 2.1. The barrel of the structure was an 8-gage multiplate steel arch composed of curved, corrugated, punched sheets bolted together to form a semicircular arched roof. The corrugations were a nominal 1-3/4 inches by 6 inches. The edges of the arch bore on and were bolted to longitudinal base channels, which were in turn lag-bolted to 2-by-6-inch timbers cast into the concrete foundation. The plates were lapped 4-7/8 inches along the longitudinal joints and were lapped one corrugation at the circumferential joints. The plates were of two different lengths in order to produce staggered longitudinal seams. The structure used for this test was taken out of Navy stock and modified by the addition of a 7-gage multiplate front-end wall duplicating the rear-end wall except that short-length plates were used.

The foundation was a 1-foot wide by 2-foot deep wall footing of reinforced concrete. The total weight of steel, excluding the entrance tunnel, was about 22,000 pounds.

A straight tunnel extending axially from one end of the building afforded entrance to the structure. This tunnel was an ARMCO multiplate pipe, 84 inches in diameter. A blast-resistant door with appropriate framing was placed in this tunnel about 3 feet from the end of the structure itself.

Figure 2.2 is a photograph of the building after placement of the earth cover. The earth berm had a trapezoidal cross section and extended axially beyond both ends of the building, as shown in Figure 2.3. The total volume of earth moved was approximately 2400 cubic yards. The fill material was taken from a point several miles from the building where the natural earth was gravel and sand mixed with the silt of the dry lake bed. The earth fill was carefully tamped to a height of 8 feet, using a sheepsfoot roller supplemented by hand tamping close to the building. The sheepsfoot roller was not permitted to approach within a foot outside a vertical plane through the springline. The earth cover above a height of 8 feet was not tamped.

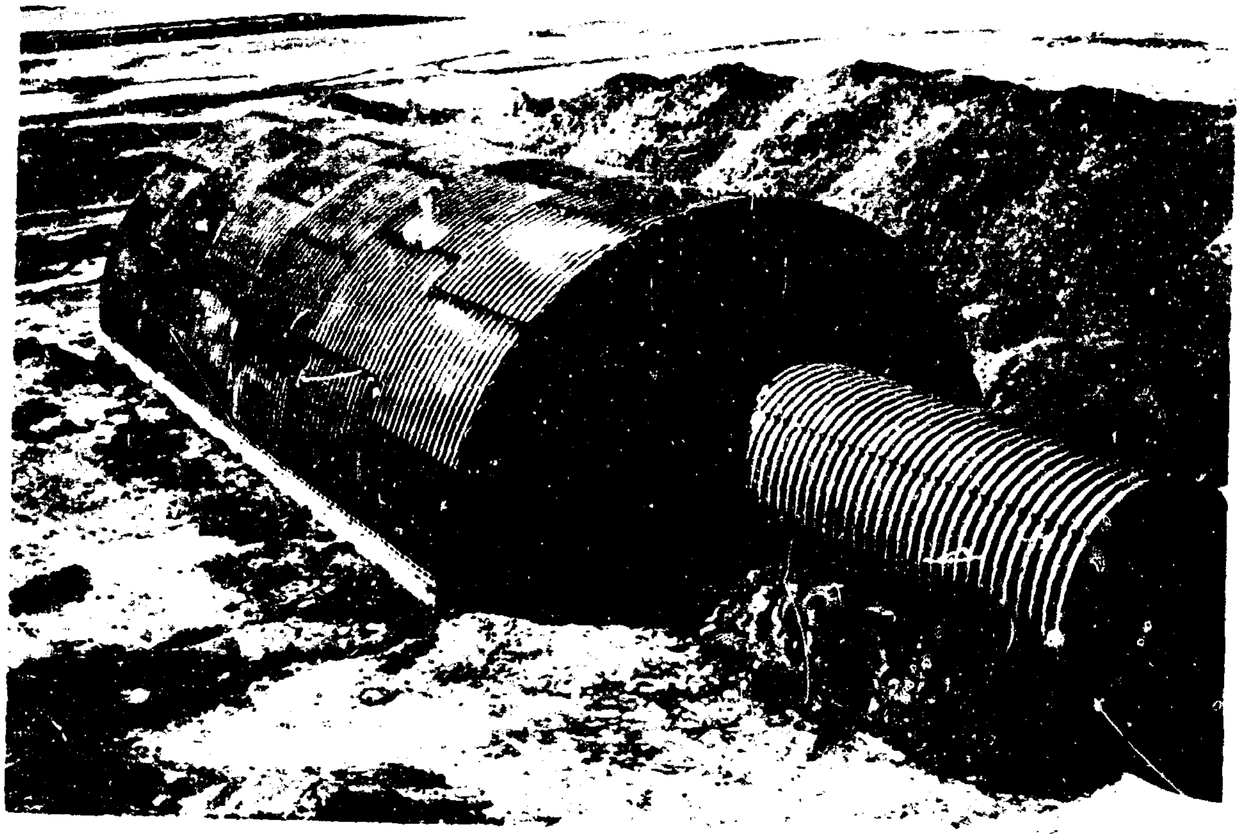


Figure 2.1 Building 3.6 without earth cover.

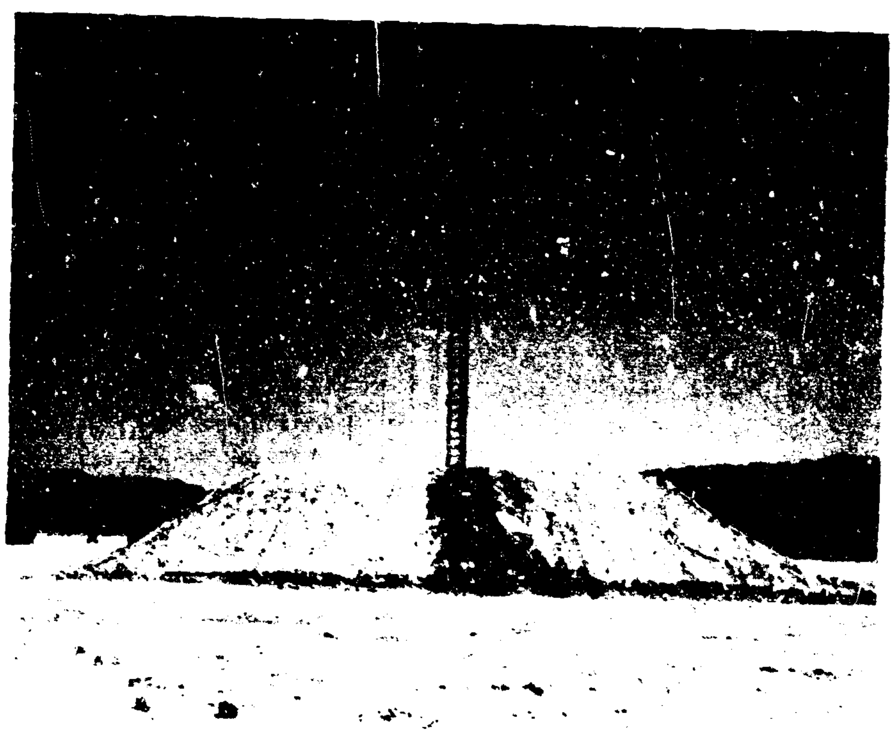


Figure 2.2 Building 3.6 with earth cover.

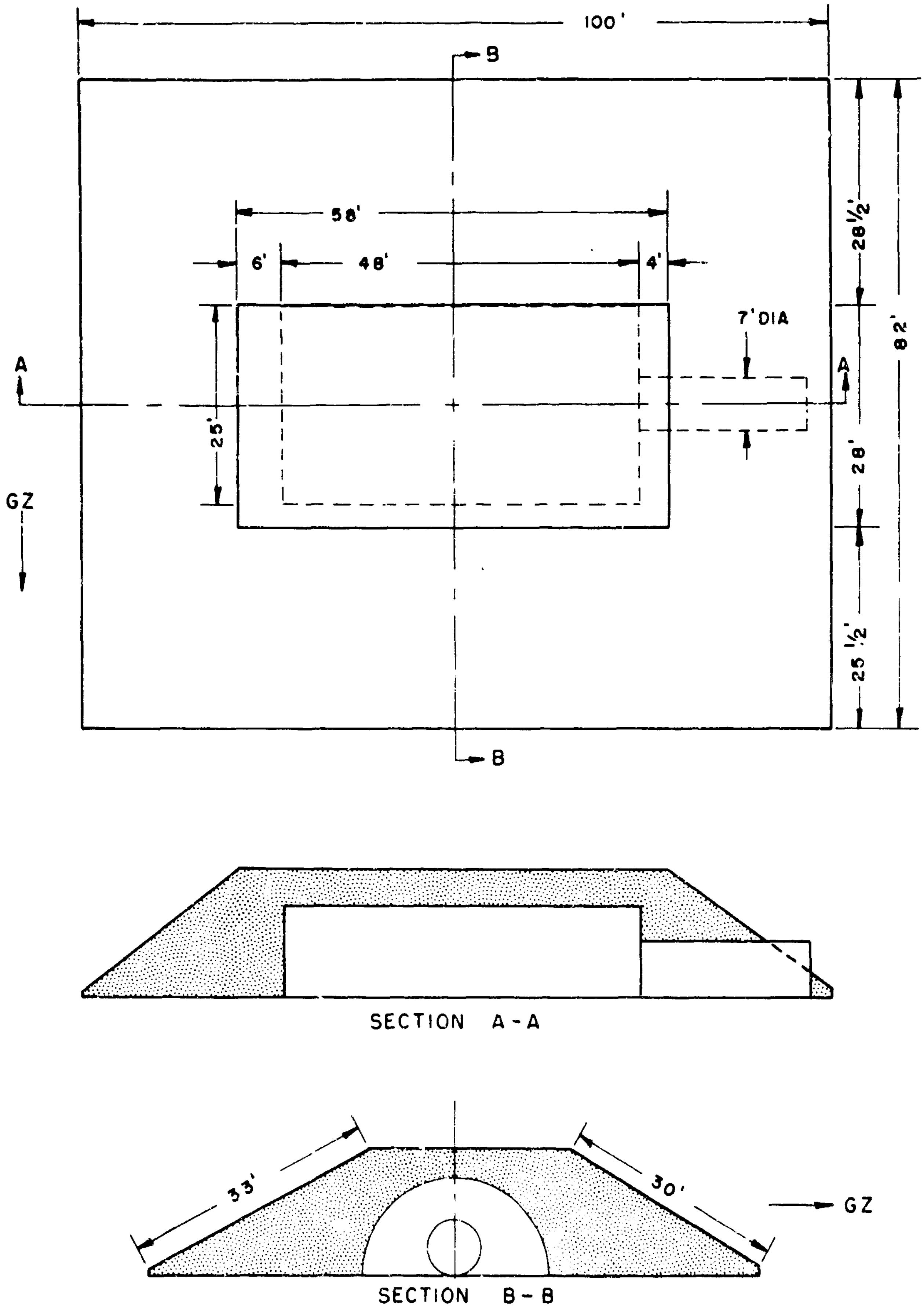


Figure 2.3 Profile of earth cover, Building 3.6.

The rear-end wall of the building was reinforced by diagonal tension bracing as indicated in the photograph and sketch of Figures 2.4 and 2.5. It is to be noted that the dead man on the outside of the building could safely be placed flush with original ground level because it had at the time of the blast both the load of some 15 feet of earth cover on it and some additional air pressure loading. As noted in Section 1.2, this reinforcement of the end wall was intended simply to strengthen the end wall for this specific test so that its performance would not interfere with the evaluation of the strength of the arch in the center plane where it is not appreciably supported by the end walls. The design of the bracing did not include consideration of the possible stresses if the building had been oriented end-on to ground zero.

Similar diagonal bracing of the front-end wall is just visible in Figure 2.1. In the case of the front-end wall, the tunnel entrance represented a considerable strengthening; hence two diagonal steel ties on each side of the tunnel were judged to be sufficient. Actually, the front-end wall bracing may represent greater importance in real shelters since any shelter should have multiple exits.

A blast resistant door and bulkhead was designed especially for this test as indicated in Figures 2.6 and 2.7. The intent in the design of these elements was, as in the design of the end-wall bracing, simply to strengthen these elements so that their performance would not interfere with the evaluation of the building as a whole. The design criterion, chosen arbitrarily before the test, was 40 psi static pressure. No measurement of the static pressure in close proximity to the door or, in fact, anywhere in the tunnel, was made but it is believed to be a satisfactory presumption that the peak pressure at the door was essentially the same as the peak side-on pressure in the open. This, as shown in Figure 4.1, was approximately 30 psi.

The use of wood in the door to withstand such short time loads is attractive because the strength of wood increases as the time of loading decreases. Wood, of course, is unattractive as a material for blast resistant structures because its failure is of a brittle type.

Placement of the hinge at the bottom of the door was a matter of convenience for this test and is not recommended as a general design for blast resistant structures where it may be necessary to close the door quickly.

2.2 BUILDING U-K 3.15

In addition to the building just described, the structure constructed for UPSHOT-KNOTHOLE Project 3.15 was also tested on TEAPOT Shot 12. This building was similar to Building 3.6 in that it was also a 25-by-48-foot steel arch manufactured by ARMCO Drainage and Metal Products, Inc., but it differed from Building 3.6 in the following respects:

1. The barrel was of a lighter gage (10-gage multiplate) and had a deeper (2-by-6-inch) corrugation.
2. The attachment of the arch barrel to the foundation was by means of J-bolts cast into the foundation.
3. The shape of the earth cover was different in that the horizontal top of the earth cover was tangent to the arch barrel at the crown.

Figure 2.4 End-wall strengthening.

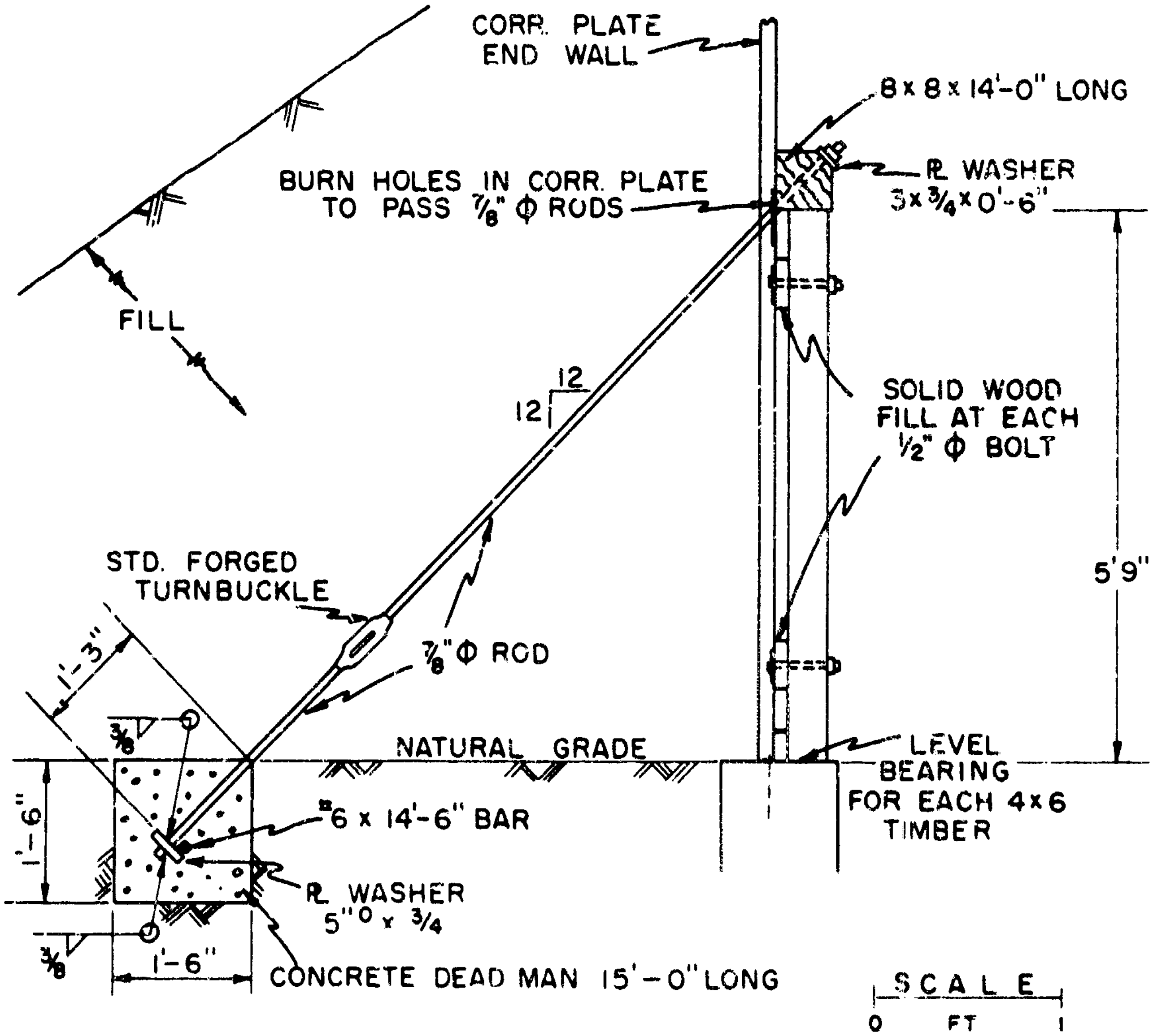


Figure 2.5 Diagram of end-wall strengthening.

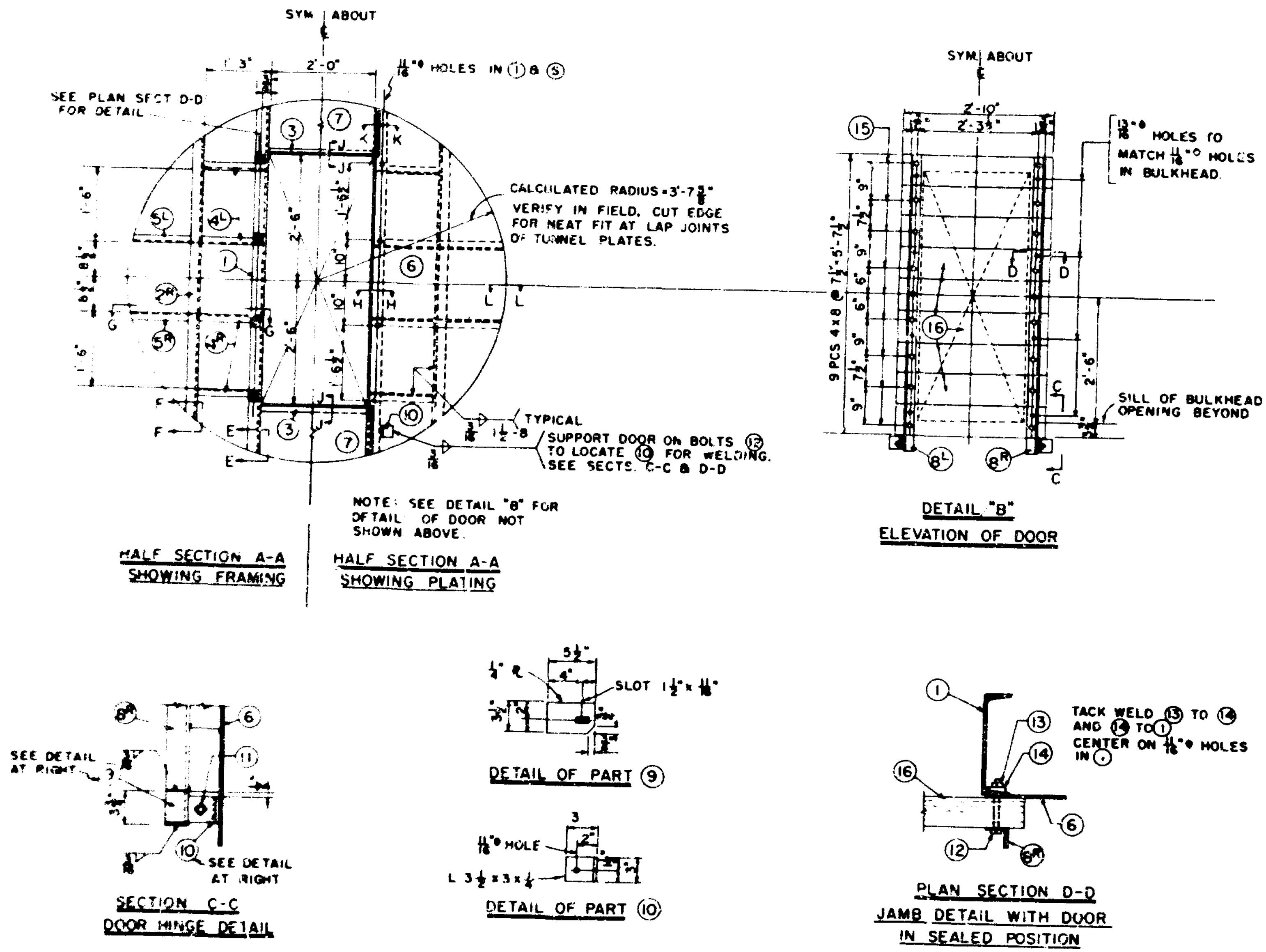
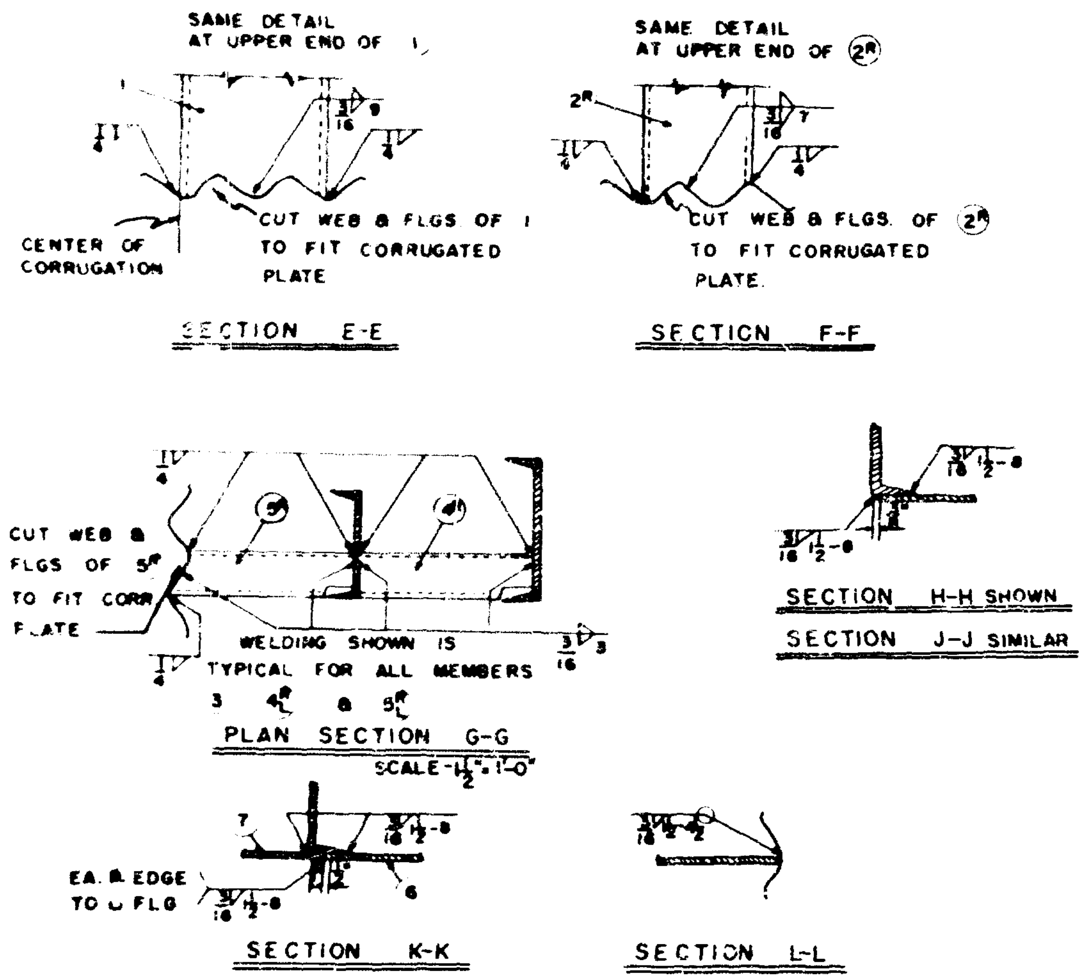


Figure 2.6 Design of blast-resistant door and framing.



BILL OF MATERIALS

MARK	REQ'D.	DESCRIPTION	REMARKS
1	2	$12 \sqcup 20^{7} \times 7'\text{-}1''$	ORDERED LG. – TRIM IN FIELD
2^R_L	2	$9 \sqcup 13^{4} \times 6'\text{-}0''$	DO. DO.
3	2	$4 \sqcup 5^{4} \times 2'\text{-}0''$	
4^R_L	8	$4 \sqcup 5^{4} \times 1'\text{-}2\frac{11}{16}''$	
5^R_L	4	$4 \sqcup 5^{4} \times 1'\text{-}4''$	ORDERED LG. – TRIM IN FIELD
6	2	PL $\frac{3}{16}$	SKETCH – SEE NOTE 2 BELOW
7	2	PL $\frac{3}{16}$	SKETCH
8^R_L	2	$\angle 2\frac{1}{2} \times 2\frac{1}{2} \times 5'\text{-}11\frac{1}{4}''$	
9	2	PL $3\frac{1}{2} \times \frac{1}{4} \times 0'\text{-}5\frac{1}{2}''$	
10	2	$\angle 3\frac{1}{2} \times 3 \times \frac{1}{4} \times 0'\text{-}3''$	
11	2	BOLT $\frac{3}{8}''\phi \times 1\frac{1}{2}''$	SQ. H & N
12	8	BOLT $\frac{3}{8}''\phi \times 6''$	SQ. H
13	8	NUT $\frac{3}{8}''\phi$	SQ. – TO FIT (12)
14	8	BEV. WASHER $\frac{3}{8}''\phi$	BEVELED FOR STD. CHANNEL FLG.
15	18	LAG. SCREW $\frac{1}{2}''\phi \times 3\frac{1}{2}''$	
16	9	WOOD $4 \times 8 \times 2'\text{-}10''$ NO. 1 D.F. S4S –	SEE NOTE 3 BELOW

ALL MATERIAL IS STEEL UNLESS OTHERWISE NOTED.

NOTES:

1. ALL STEEL MATERIAL AND WORKMANSHIP SHALL CONFORM TO A.I.S.C. SPECIFICATIONS.
2. PLATES (6) MAY BE SPLICED ON CHANNELS (2L) WITH DETAIL SIMILAR TO SECT. K-K, IF DESIRED TO FACILITATE HANDLING.
3. WOOD FOR DOOR SHALL BE THOROUGHLY SEASONED BEFORE FABRICATION.

Figure 2.7 Design of blast-resistant door and framing.

TABLE 2.1 STRUCTURAL PROPERTIES OF BUILDING 3.6 AND MODELS

	Prototype	Steel Models			Aluminum Models		
Property	Magnitude	Magnitude	Actual Ratio	Desired Ratio	Magnitude	Actual Ratio	Desired Ratio
Arch Diameter (ft)	25	6.25	1/4	1/4	6.25	1/4	1/4
E (psi)	30×10^6	30×10^6	1	1	11×10^6	1/2.74	1/4
I(in^4/ft)*	0.922	0.0210	1/44	1/64	0.0172	1/54	1/64
I/c(in^3/ft)*	0.958	0.0801	1/12	1/16	0.0656	1/15	1/16
Section Area (A) (in^2/ft)*	2.38	0.639	1/3.7	1/4	0.523	1/4.5	1/4
Yield Strength (Sy) (kips/in^2)	32.9	35.1	1.07	1	11.85	1/2.8	1/4
Ultimate Strength (kips/in^2)	45.5	43.5	0.955	1	16.7	1/2.7	1/4
$\frac{1}{IE}$	3.62×10^{-8}	1.59×10^{-6}	44	64	5.29×10^{-6}	146	256
$\frac{\text{Size Ratio}^4}{IE}$**	3.62×10^{-8}	0.621×10^{-8}	1/5.9	1/4	2.07×10^{-8}	0.57	1
A Sy***	78.4	22.4	1/3.5	1/4	6.19	1/19	1/16
$\frac{I}{C}$ Sy****	31.5	2.82	1/11	1/16	0.779	1/40	1/64

* Per foot of barrel length
** Deflection (below yield) for a given psi loading varies approximately as $(\text{Size Ratio})^4/IE$
*** Direct load capacity at failure varies as A Sy
**** Bending capacity at failure varies as $\frac{I}{C}$ Sy

In addition, the earth cover for Building U-K 3.15 was the silt peculiar to the dry lake at Frenchman Flat and the thickness of the earth cover at the sides of the arch barrel was somewhat less.

4. The end walls were not reinforced.

2.3 MODELS

In addition to the two full-scale structures, six models were used. All of these were scaled to approximately one-quarter the size of Building 3.6 and were constructed of sheet metal corrugated to a nominal 2.5 by 0.5 inches. Three were steel and three were aluminum. The properties of the models compared to those of the prototype are shown in Table 2.1.

These models were covered with an earth berm similar to that used on Building 3.6 except that no compaction was attempted. Figure 2.8 is a photograph of one of these models without earth cover, and Figure 2.9 is a picture of one of the models during placement of the earth cover.

2.4 INSTRUMENTATION

The radius from TEAPOT Shot 12 ground zero to each unit is shown in Table 2.2.

Four deflection gages were used to determine the shape and movement of the center section of the barrel arch of Building 3.6. These gages measured the change in length of four chords in the central plane of the building. These four chords are those indicated in Figure 4.8. The gages themselves were BRL units. The remote recording was accomplished by Stanford Research Institute (SRI), using a 3000-cps carrier voltage, Wiancko demodulators, and Miller oscillographs. An SR-4 resistance-wire strain gage was placed to measure total compressive strain at the crown. This strain was remotely recorded.

TABLE 2.2 LOCATIONS OF BUILDINGS AND MODELS

Unit	Material	Radius from GZ (ft)
Building 3.6	Steel	1,500
Model No. 1	Steel	1,400
Model No. 2	Steel	1,500
Model No. 3	Steel	2,000
Model No. 4	Aluminum	2,000
Model No. 5	Aluminum	2,500
Model No. 6	Aluminum	3,000
Building U-K 3.15	Steel	2,300

Nine self-recording BRL air-pressure gages were placed on the earth berm; three were placed on the windward slope, three on top, and three on the leeward slope. In addition, two remote-recording airblast gages were placed on the earth berm, one on the windward face and one on the leeward face.

A reinforcing steel rod, 42 inches long, was welded in a vertical position at the crown of the arch, 6 inches from each end wall. These rods served as reference points in determining any changes in the thickness of the earth cover.

Seven scratch gages were placed around the inside of the arch as a backup to the dynamic deflection gages. These are shown in Figure 2.10.

In addition to this instrumentation of Building 3.6, three further sets of information were obtained: (1) two scratch gage records were made of Building U-K 3.15; (2) each of the models was instrumented to obtain both permanent and maximum deflection of the crown in the center plane of the arch; and (3) radiation measurements were made both in Building 3.6 and in Building U-K 3.15.

The total dose of radiation at two locations inside each of these buildings was measured using instruments provided by the Army Chemical Corps, Project 2.7.1. The two locations in each building were at points 7 feet from the end wall to which the entrance tunnel was attached; one location was 7 feet from the windward wall, the other 7 feet from the

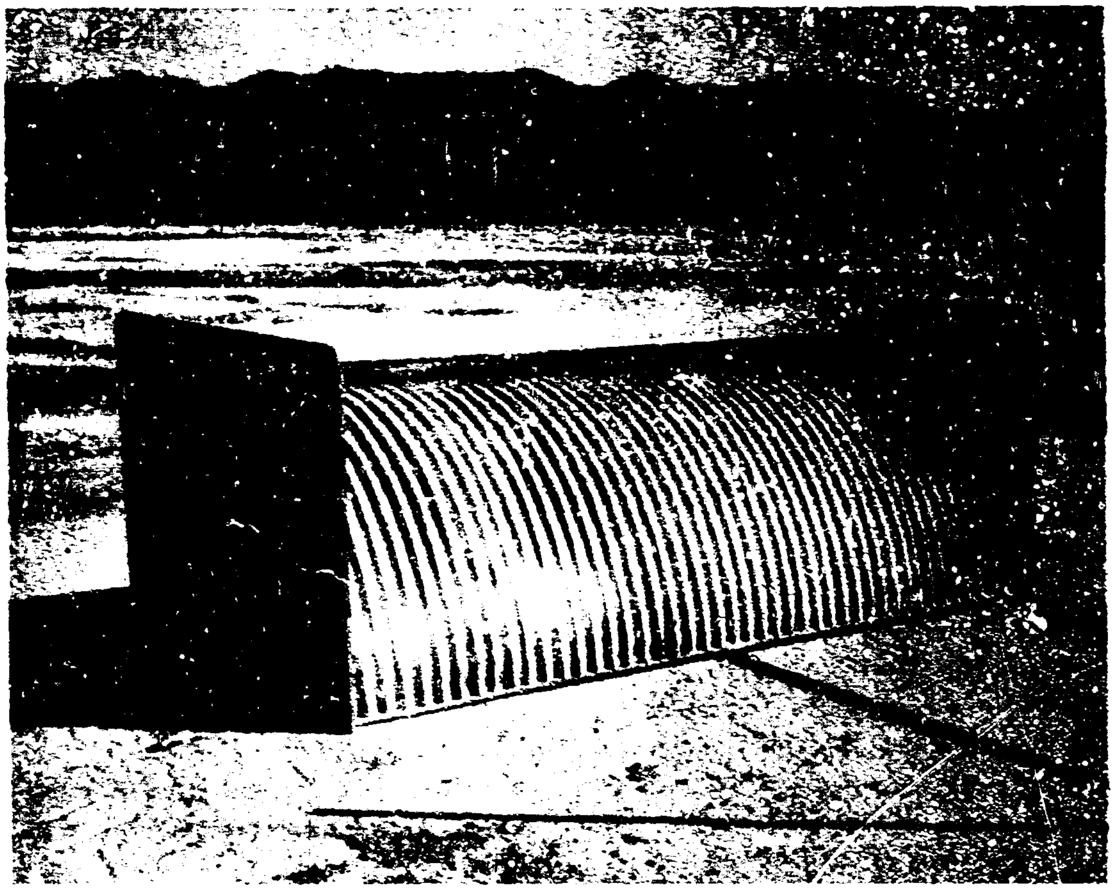


Figure 2.8 Model without earth cover.

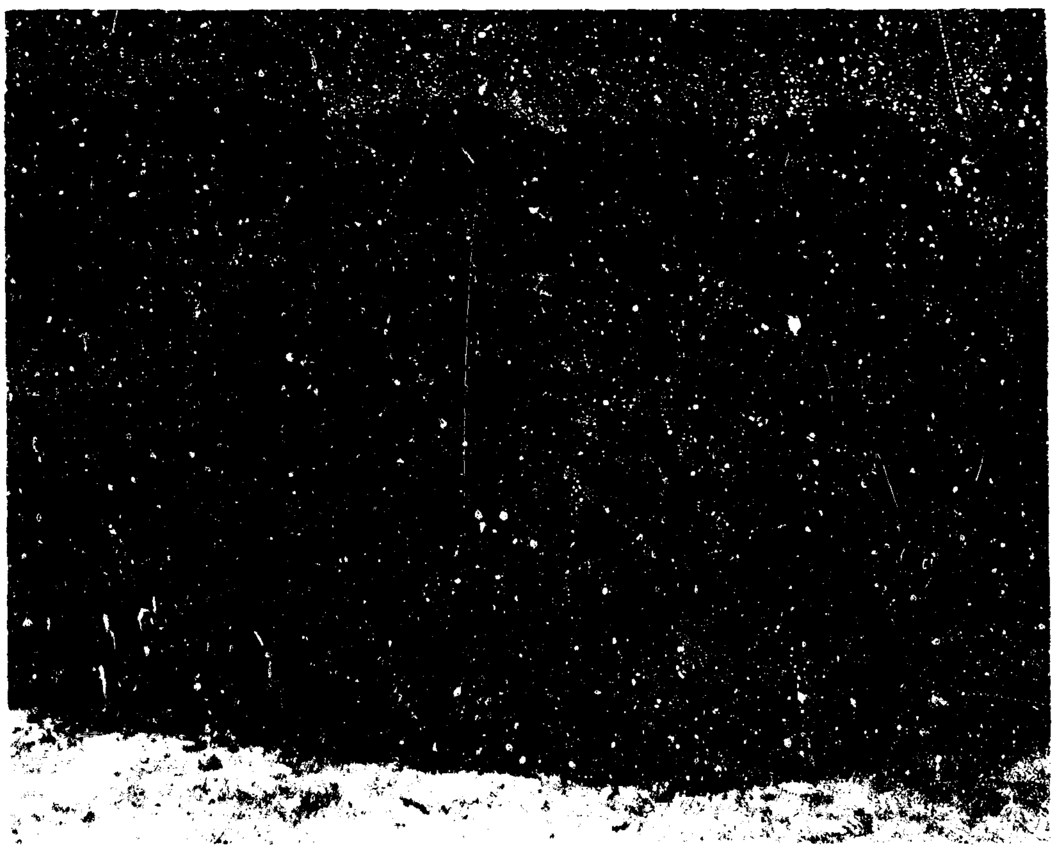


Figure 2.9 Model partially covered.

Figure 2.10 Scratch gages, Building 3.6.

leeward wall. The instruments were 20 inches and 38 inches above ground level.

At each location three types of detectors were placed. A gold-foil detector measured the total dose of thermal neutrons having energies less than 0.4 ev. A sulfur detector measured the total dose of fast neutrons above a 3-Mev threshold. Finally, a group of National Bureau of Standards film badges and chemical dosimeters were used to measure the gamma-ray dose. Some of these were shielded by lithium to reduce the undesired influence of neutrons.

Chapter 3

FIELD OPERATIONS

3.1 BUILDING 3.6

The erection of Building 3.6, complete with tunnel and blast-resistant door, was accomplished during February 1955. The earth fill was completed on 2 March 1955. The manufacturer's standard specification for construction was followed, in general, in placing the earth cover. The fill was placed in layers not over 6 inches thick and was compacted by a sheepsfoot roller to a height of 8 feet. The placement of the earth fill and movement of the compacting equipment were carefully regulated to maintain the circular shape of the barrel arch within close limits. The deflection history of the building during backfilling is shown in Table 3.1 (Reference 2). To measure the building deflection, nine gages were placed, three in each of three parallel vertical planes perpendicular to the longitudinal center line of the building at the center and quarter points of the structure. The gages in each of the three planes were arranged to measure radial deflection in planes having elevations of 45°, 90°, and 135° measured from 0° at the windward springline.

The earth fill above the structure was dampened by a sprinkler during placement and was wet down several times after its placement and prior to the shot to settle the surface level further. The results of the soil tests are reported in Table 3.2 which is quoted verbatim from Reference 2.

3.2 MODELS

The six models were constructed and placed in the field in February 1955 during the interval when the main building was being covered. The earth cover on the models was not compacted, but it was dampened by a sprinkler during its placement and, after placement, was wet down several times.

3.3 BUILDING U-K 3.15

In preparation for TEAPOT Shot 12, Building 3.15 of UPSHOT-KNOTHOLE

TABLE 3.1 DEFLECTION OF BUILDING 3.6 CAUSED BY EARTH FILL

"Plus" indicates outward deflection of the building and "minus" indicates inward deflection. "Windward" refers to the side toward ground zero and "leeward" refers to the side away from ground zero.

Static strains were recorded for similar shelters studied for UPSHOT-KNOTHOLE (Reference 3). The crown deflection noted in Table 3.1 lies between that observed on two buildings reported in Reference 3. Correcting for gage and depth of corrugation maximum static stress in Building 3.6 under earth cover was estimated to lie between 1,200 psi and 1,400 psi.

		Deflection (inches)				
Location	Gage No.	No Fill	Fill 8 feet above Springline	Fill 1 foot above crown	Completed Fill 3 feet above Crown	24 hours after Completion of Fill
Transverse Plane through Quarter Point nearest Tunnel End						
Windward	1	0	-0.64	-0.62	-0.40	-0.58
Crown	2	0	+1.28	+1.08	+0.78	+0.94
Leeward	3	0	-0.86	-0.82	-0.76	-0.84
Transverse Plane through Center Point						
Windward	4	0	-1.21	-1.16	-0.96	-1.06
Crown	5	0	+2.18	+1.92	+1.66	+1.68
Leeward	6	0	-1.36	-1.28	-1.32	-1.34
Transverse Plane through Quarter Point nearest Closed End						
Windward	7	0	-0.94	-0.88	-0.76	-0.80
Crown	8	0	+1.48	+1.18	+1.00	+1.06
Leeward	9	0	-0.92	-0.82	-0.96	-0.96

TABLE 3.2 SOIL ANALYSIS

Samples were taken of the earth fill material as it was being placed. The samples were taken by members of the staff of the U. S. Naval Civil Engineering Research and Evaluation Laboratory, Port Hueneme, Calif., and the samples were returned to that laboratory for analysis.

Soil Classification	Brown sand, well-graded from very fine to very coarse, random stones to 5-inches diameter	
Sieve Analysis	Sieve Size	Cumulative Percent Retained
	3/8 inch	5.0
	#4	11.7
	#10	21.2
	#20	33.2
	#40	44.9
	#60	58.4
	#140	84.1
	#200	91.2
Specific Gravity	2.64	
Compaction Test	Modified AASHO - 10-pound hammer, 18-inch drop. 5 layers, 1/30 ft^3 cylinder	
	Maximum dry density	124 lb/ft^3
	Optimum moisture content	11 percent
Triaxial Shear Test on Dry Sample	Percent compaction	86 percent
	Angle of internal friction	39.5°
	Cohesion	2.0 lb/ft^2
Field Density Tests	Average dry density of compacted backfill from footings to height of 8 feet	110 lb/ft^3 (88.8 percent of maximum)
	Average dry density of uncompacted backfill above height of 8 feet	108 lb/ft^3 (87 percent of maximum)
	Average moisture content of backfill	7 percent

was modified and instrumented as follows: the cross tunnel was removed (for use as the entrance tunnel on Building 3.6); the holes in the arch roof were patched by welding; the two scratch gages used in the building during Operation UPSHOT-KNOTHOLE were reinstalled; and radiation detection equipment was installed.

Incontrovertible evidence was found that a cat had scrambled on the hot tin roof of this building. Tracks were apparent in the thin layer of soil close to the crown and clear scratches were found in the galvanizing of the steel itself. Extensive questioning of witnesses established that the cat was a D8, weighing 40,000 pounds, which had been driven onto the building during the removal of the cross tunnel.

Chcpter 4

RESULTS

4.1 SUMMARY

The dynamic pressures produced by Shot 12 at the close-in ranges of most interest to Project 3.6 were considerably larger than had been predicted. The main structure of Project 3.6 was collapsed by these forces, but there is support for the belief that it would have withstood the predicted values successfully.

Radiation measurements inside Building 3.6 indicated a total gamma dose somewhat above the lethal dose and a neutron dose less than the lethal value.

The performance of the models was in accord with predictions. Of the three steel models which were intended to collapse at the same values of applied external pressure as Building 3.6, the two at 1,400 feet and 1,500 feet, which received pressures similar to or larger than those applied to Building 3.6, collapsed. The one at 2,000 feet, which received roughly one-third the pressure applied to Building 3.6, remained standing. Of the three aluminum models which were expected to fail under pressures roughly one-quarter of those which would produce failure in the main building, the one at 2,000 feet, where the pressure was on this basis roughly twice that expected to produce failure, did fail. Those at 2,500 feet and 3,000 feet, where the maximum pressures were less than one-quarter those applied to Building 3.6, remained standing.

Building U-K 3.15 withstood forces of 15 percent of those applied to Building 3.6, with trivial deflections.

Comparison of the radiation measurements in Building U-K 3.15 with those in Building 3.6 demonstrated the value of the 3 feet of earth cover above the crown of such a structure.

4.2 BLAST EFFECTS

Results of operations previous to TEAPOT suggested that some important anomalies in the blast effects from Shot 12 of Operation TEAPOT were to be expected. Measurements made on TEAPOT Shot 12, reported in detail in References 4 and 5, showed that over a desert surface the

dynamic pressure q is, at the distances of interest, considerably larger than the ideal value, while the value of the overpressure p is significantly less than its ideal value. The ideal value is defined briefly as the value which would occur with no thermal effects over a perfect reflecting surface with no dust. Actually the peak value of the dynamic pressure at 1,500 feet was higher than the upper limit of its expected value including the maximum uncertainty judged to exist in the prediction.

Figure 4.1 presents the measurements of the blast effects from Shot 12 in the open on the desert line at 1,500 feet. The peak dynamic pressure of 160 psi shown on Figure 4.1 at a 10-foot height is equivalent to a wind velocity of about 3,000 mph in clear air at sea level. It will be noted from this figure that: (1) the dynamic pressure was much larger than the side-on overpressure; (2) all the pressure curves show two major peaks separated by the order of 100 or 200 msec; and (3) there is a significant difference between measurements taken at a 3-foot height and those at a 10-foot height. In addition, it should be remarked that the curves shown on this figure have been considerably smoothed in the data-processing procedure. The original gage records, as reproduced in Reference 4, show numerous short-time variations having periods ranging between 2 and 10 msec. Both these short-time variations and the apparently unrelated differences in the q measurements at 3 feet and 10 feet may well have been the result of severe turbulence.

It should be noted that the data on blast effects in the open which have been used for this report have been taken from the results of Project 1.10. As indicated in the report of that project (Reference 4), there is a significant uncertainty in the precision of the q values reported, particularly in the regions of high pressures, such as existed at 1,500 feet. The sensitivity of the q gages (in this case, pitot-tubes) to dust is not well established. In addition, the corrections to the gage readings for high Mach numbers and large pitch angles are not well established and become, in some of the peak values of interest in this report, as large as 30 percent or more.

4.2.1 Building 3.6. When the air blast from Shot 12, (whose effects in the open are shown in Figure 4.1) passed over the earth berm covering Building 3.6, it produced pressures on the sides and top of the earth berm as shown in Figure 4.2. The gage positions of the records shown there were numbered in sequence from 1 at the windward toe to 9 at the leeward toe; thus Positions 1, 2, and 3 were on the windward slope, Positions 4, 5, and 6 (of which records from 4 and 5 were lost) were on the horizontal top, and Positions 7, 8, and 9 on the leeward slope (gage 8 was also lost).

At all nine positions, BRL self-recording gages were placed. In addition, at Positions 3 and 7, SRI remote-recording gages were placed. In the processing of the records, the BRL record time scales were expanded or contracted as necessary in order to develop the best fit of the records at Positions 3 and 7 with the SRI records at those stations. No adjustment of the pressure scale was made. In adjusting the time scale of the BRL records the following procedure was used:

1. On records for Positions 3 and 7, the arrival time of the first rise on the BRL record was placed identically with the corresponding

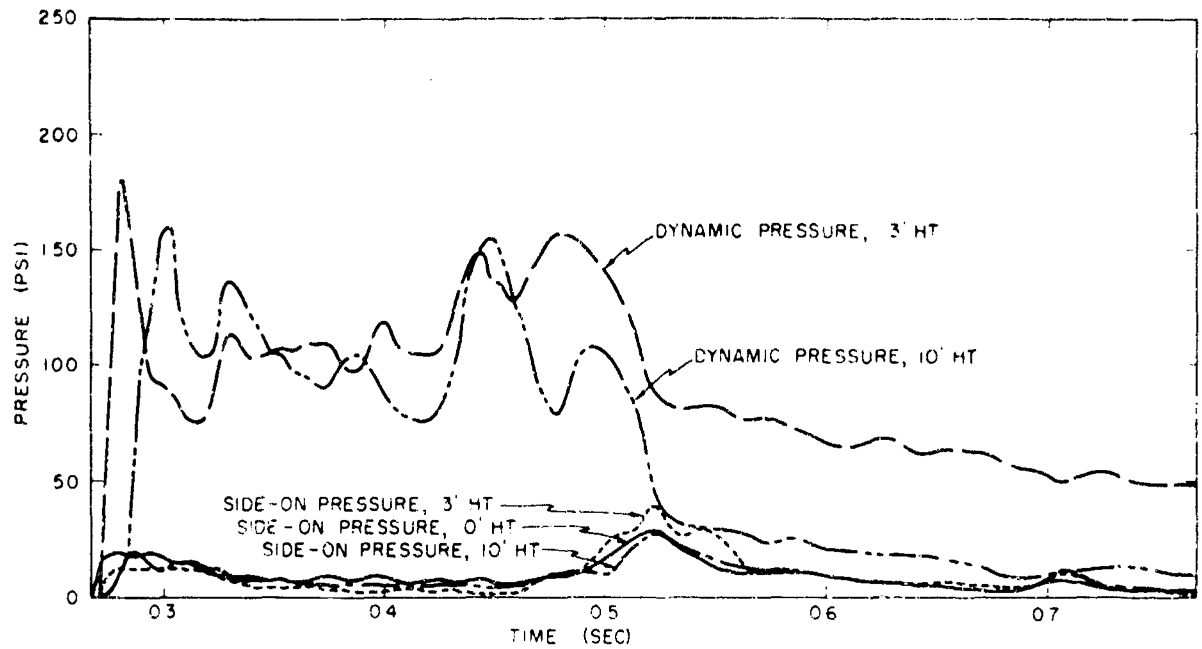


Figure 4.1 Pressure-time, desert line, 1,500 feet.

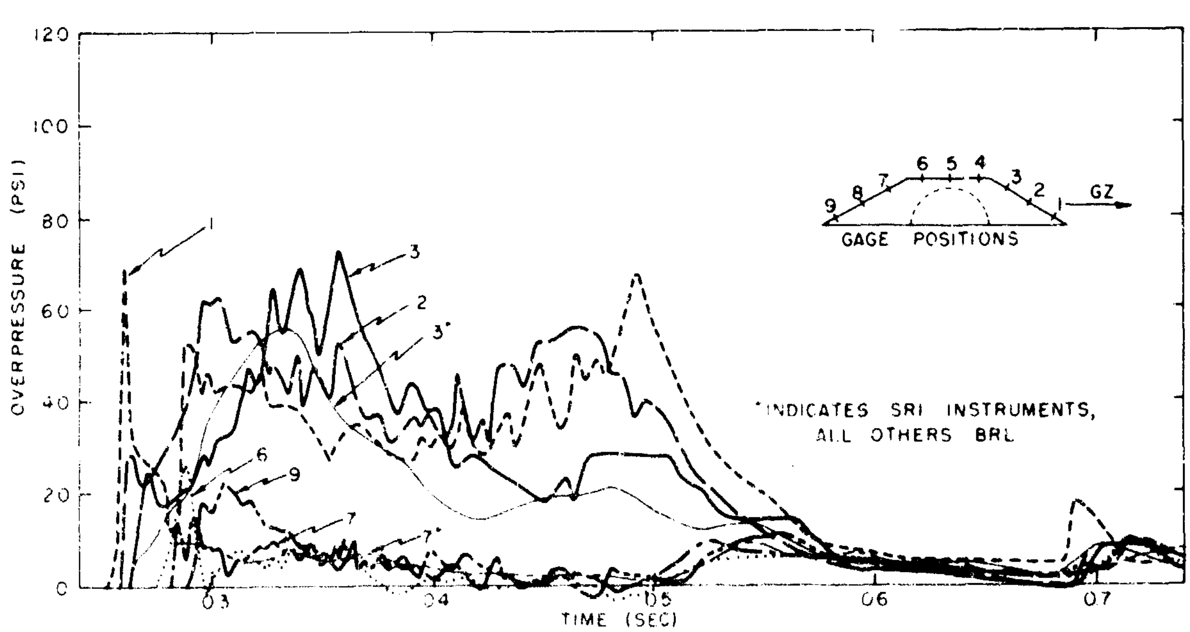


Figure 4.2 Pressure-time, earth berm, Building 3.6.

arrival time shown on the SRI record.

2. The arrival of the bump at approximately 0.7 second on each of these BRL records was adjusted to coincide with its arrival on the corresponding SRI record.

3. The two SRI-determined values of first arrival and bump arrival times were plotted vs. horizontal distance, and a linear extrapolation was then used to obtain first and second arrival times for the remaining BRL gages.

As has been noted, for two of the three gages on the top of the earth berm, and for one of those on the leeward side, no record was recovered; also, the uppermost gage on the windward slope (at Position 3) was thrown approximately 40 feet (presumably during the interval of severe wind velocities). It is clear that extensive motion of the earth berm occurred in the interval of 300 msec after blast arrival and it is thus entirely possible that any of the pressure gages may have tilted and therefore may not have recorded the true pressure normal to the surface throughout the whole time of interest. While the gages at Position 3 are most suspect in this regard, no serious anomalies appear in their records.

Among the elements of interest on Figure 4.2 are the following: (1) the pressure on the windward slope reached maximum values of the order of 70 psi (10,000 lb/ft^2) and was maintained in the range of 40 psi or above for approximately 1/4 second; (2) the pressures on the leeward slope were, in comparison, altogether trivial; and (3) the arrival times of the peak pressures on the slopes bear very little relation to the arrival times on the blast line of either the peak overpressure or the peak dynamic pressure.

The movement of the earth berm under the influence of these forces is shown by the comparison of Figures 4.3 and 4.4; the movement of the building is shown in Figures 4.5 and 4.6, and also by the deflection gage records in Figure 4.7. From these deflection curves, the building profile at various times after the blast wave arrived was computed and is presented in Figure 4.8. With the arrangement of deflection gages shown in Figure 4.7, a precise location of the crown at each instant is determined by gages 4DV and 4DY. In making use of the records from the other two wire deflection gages (4DW and 4DX) it has been assumed that the length of the steel arch measured along the arc itself remains constant. In other words, it has been assumed that the steel did not stretch or shrink and that no slippage occurred at the bolted joints. Since on Operation UPSHOT-KNOTHOLE a similar building (U-K 3.15) under considerably smaller loading was found to have reduced its circumference by approximately 1 inch, it is quite likely that this presumption of no change of length in the arch is not altogether valid. However, the actual slippage of the joints can hardly have exceeded 1 inch, and shortening of the arch in this amount would not change the general character of the deflection performance of the building.

In performing the analysis leading to the profiles shown in Figure 4.8, several alternative shapes of profile were considered. In choosing between them, an analysis was made of the pressure required to produce the assumed movement of the building at the point of maximum displacement, together with the same movement of a rectangular section of the

Figure 4.3 Earth berm, Building 3.6, before shot.

Figure 4.4 Earth berm, Building 3.6, after shot.

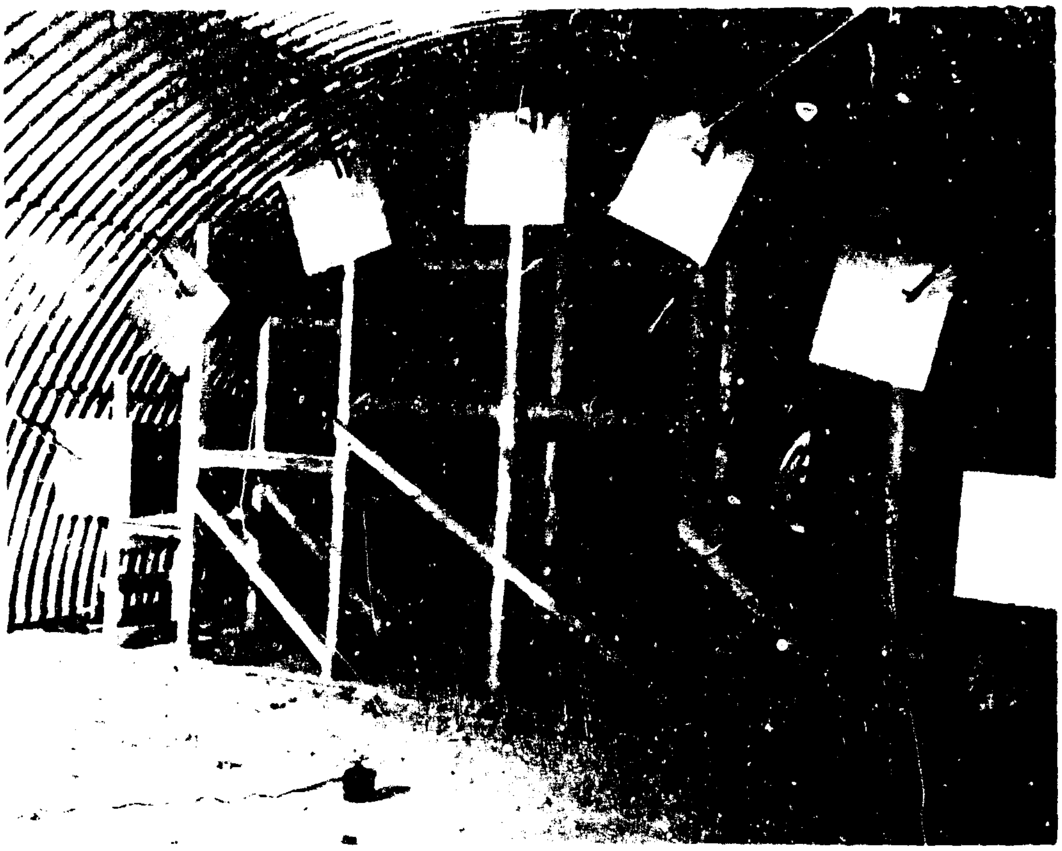


Figure 4.5 Interior of Building 3.6, before shot.

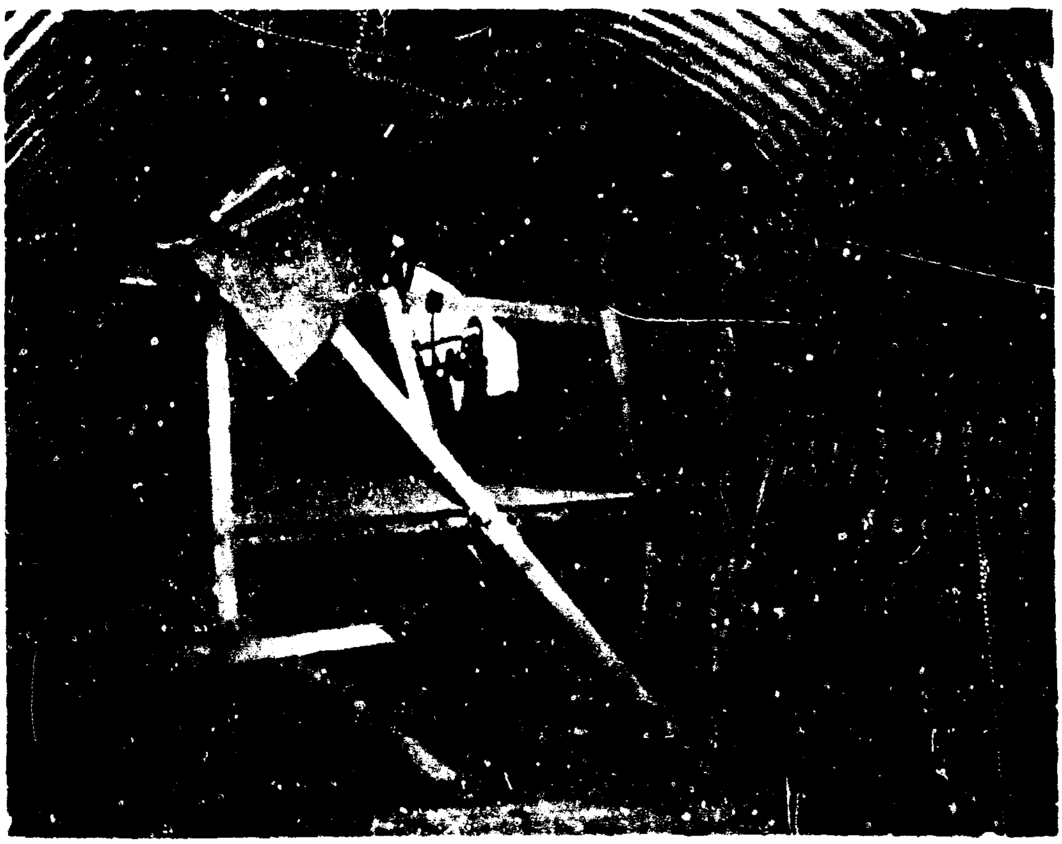


Figure 4.6 Interior of Building 3.6, after shot.

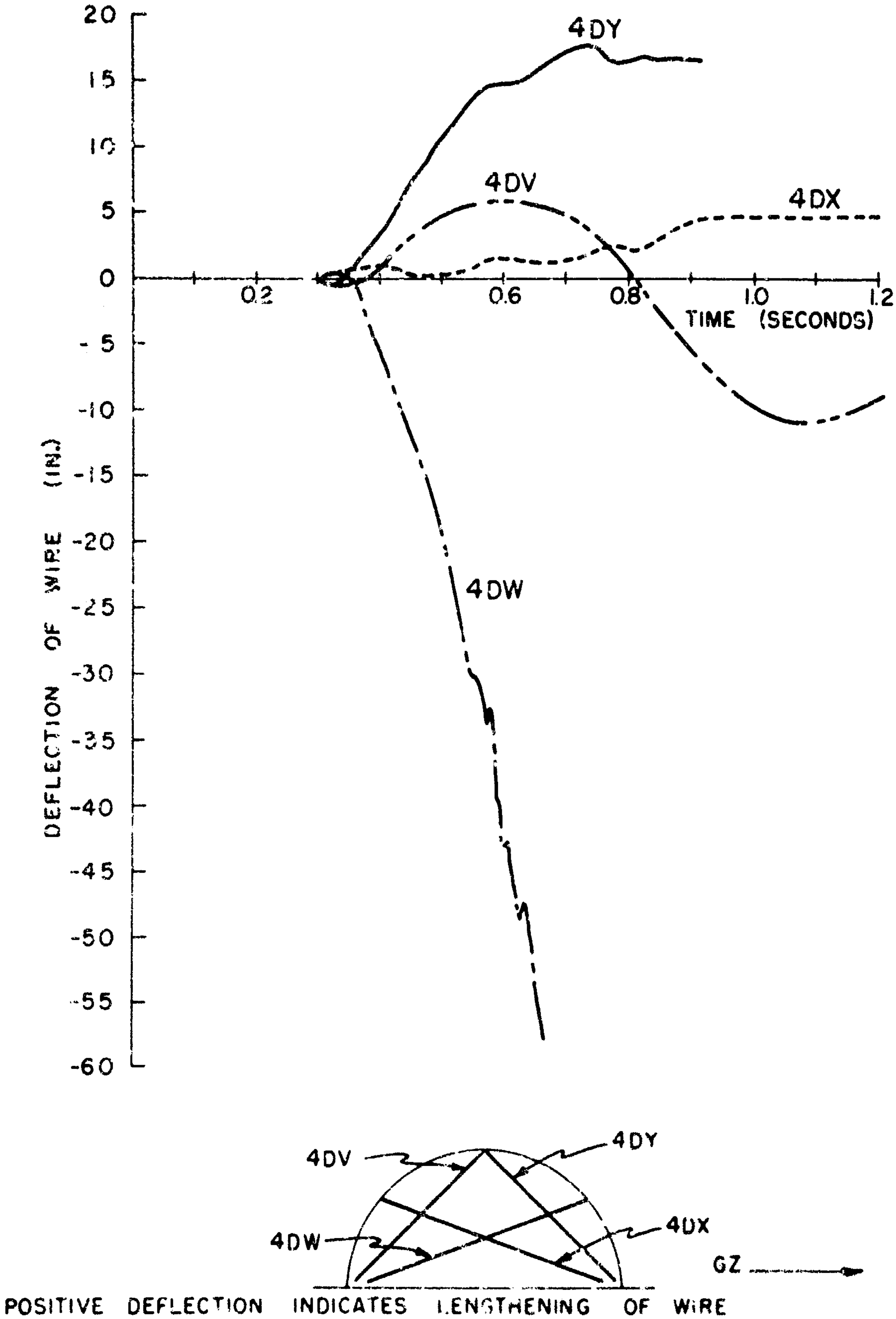


Figure 4.7 Deflection gage records, Building 3.6.

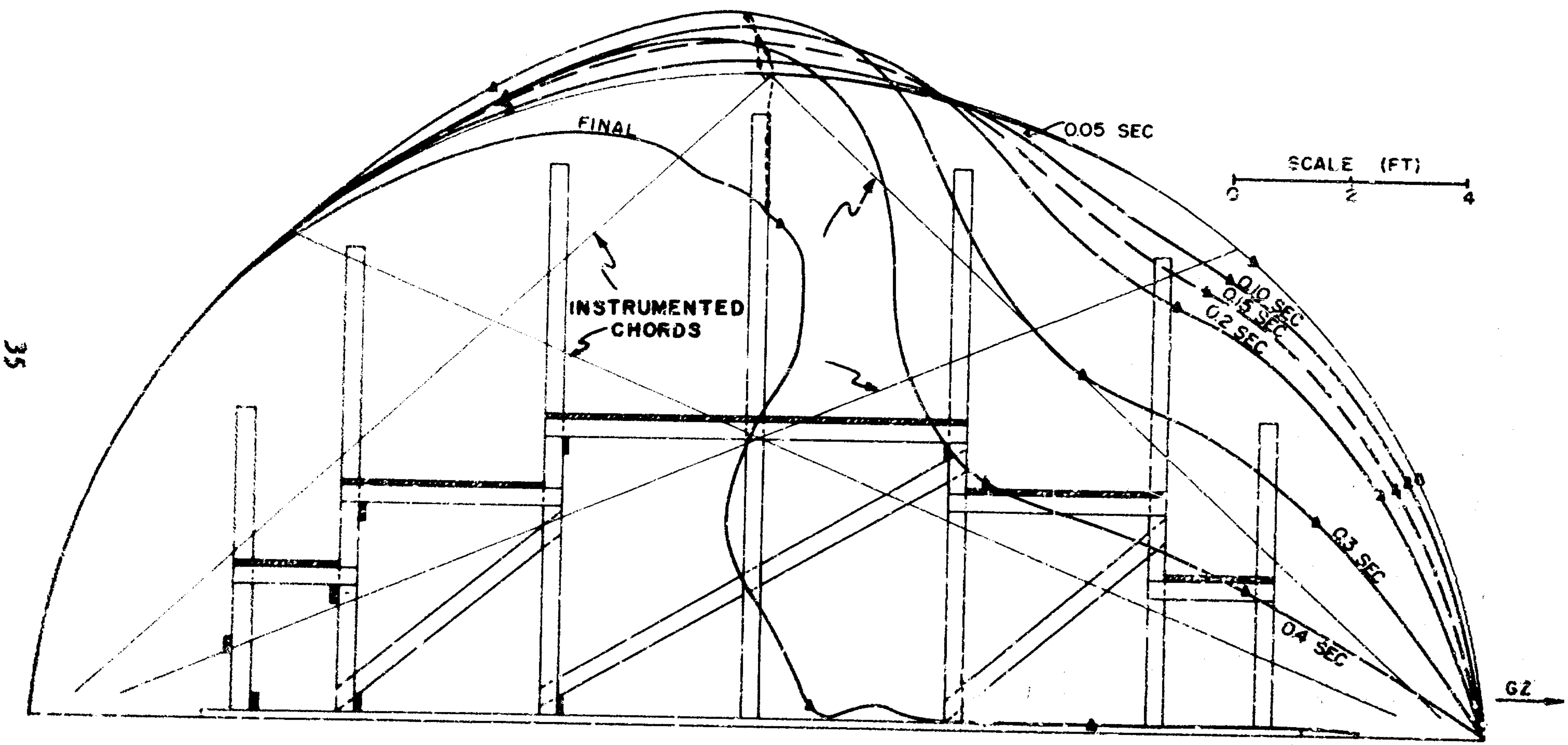


Figure 4.8 Profile at various times, Building 3.6.

earth berm extending from the building to the surface. Since the earth cover was approximately 10 feet thick at this point and weighed 108 lbs/ft^3, it can be shown that to produce an acceleration of Z ft/sec^2 a pressure of 0.2325 Z psi would be required.

This situation can be thought of as assuming that no resistance to acceleration is offered by the building or by shearing of the earth cover. In the first instant after the blast wave arrives this assumption is valid. Alternatively, one can think of this situation as stating simply that the net driving force, namely the external pressure less the resistance of the structure and the earth cover, converted to pounds per square inch, is the driving force and is related to the acceleration by the factor 0.2325.

Figure 4.9 shows the results of the analysis of Figure 4.8 by the following procedure. First, on Figure 4.8 a line was drawn connecting the points of maximum movement of the arch. Along this line the displacements as a function of time were measured. The velocity during each time interval was then computed from these figures and has been plotted on Figure 4.9. A rough differentiation of this curve was performed to determine the curve of acceleration-versus-time shown there. This indicates that the maximum acceleration was approximately 330 ft/sec^2, which corresponds to a maximum pressure of 77 psi. The measured pressures as shown in Figure 4.2 are approximately 70 psi. For times greater than 0.2 second, this figure indicates a roughly constant acceleration of about 82 ft/sec^2, which corresponds to a net pressure of 19.2 psi (or if gravity is assumed to be effective by the time the building has deflected to so great an extent, then only 11.6 psi are required to produce this acceleration).

The significance of the analysis indicated in Figure 4.9 is simply to confirm the reasonable nature of the assumptions required in the development of Figure 4.8 from the measured displacements shown in Figure 4.7. Actually Figure 4.8 was drawn in the form shown here because this analysis performed on the alternative forms for Figure 4.8 did not show the same good comparison with the actual pressures applied.

The seven scratch gages which were placed in the central plane of the arch were intended to serve as backup instrumentation in case of failure of the primary instruments. Since the primary instrumentation, specifically the wire deflection gages, operated with completely satisfactory results, the scratch gages were not necessary. In addition, however, during the course of the failure of the building, the platform on which the scratch gages were based was destroyed. As a result the interpretation of the scratch-gage records is quite complicated as well as being somewhat unnecessary. It therefore seemed more appropriate to make use of the scratch gage records as confirmation of the results described in Figure 4.8, rather than as any part of the primary data. With this point of view in mind, Figures 4.10 and 4.11 were prepared, in which the dashed lines represent the movement of the appropriate element of the arch as taken from Figure 4.8. This is to be compared with the solid line in each case, which is the actual line scribed by the scratch gage. In Figures 4.10 and 4.11, at the start, of the record for each gage a solid guide line representing the tangent to the building at that point has been drawn. In addition, to assist the reader further, an

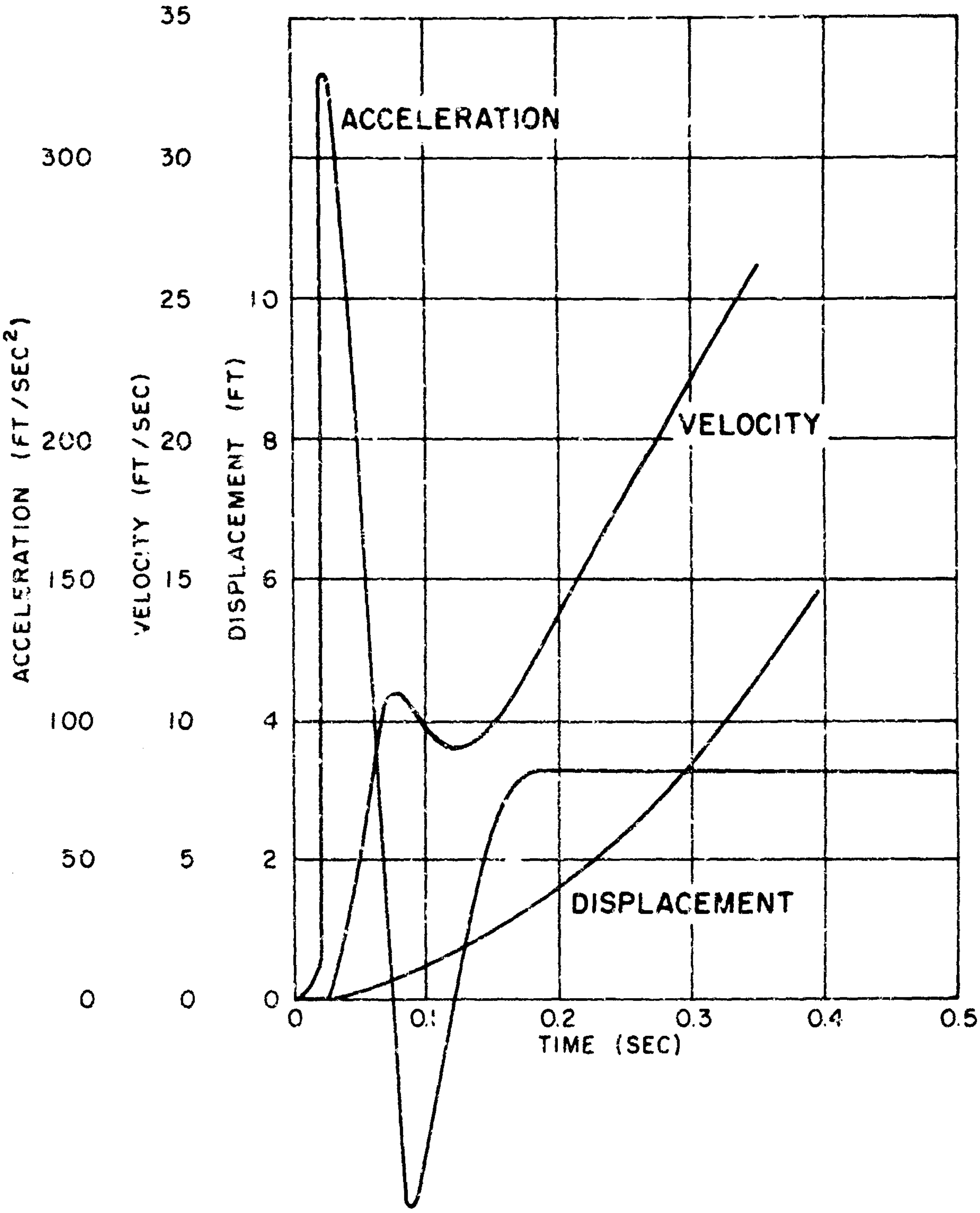


Figure 4.9 Approximate response of the windward haunch, Building 3.6.

arrow has been drawn along the radius of the arch pointing toward its center.

Since, as indicated in Figure 4.8, the platform on which the scratch gages were placed began to be seriously distorted at approximately 0.15 second after the blast wave arrived, on the scratch gage records in Figures 4.10 and 4.11 the correlation between the gage record itself and the dashed line taken from Figure 4.8 should be expected to depart more and more after 0.15 second. It will be noted that, in general,

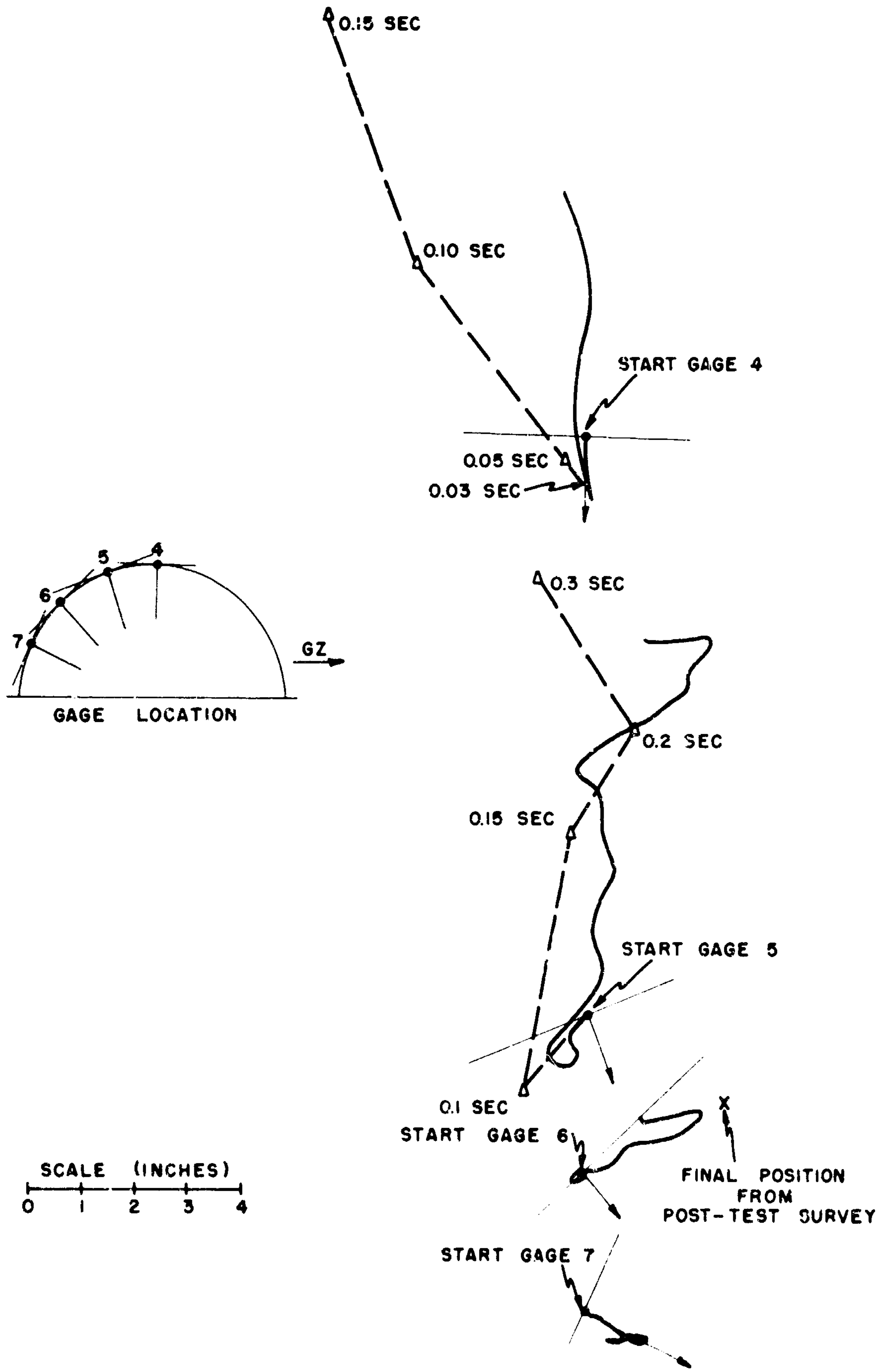


Figure 4.10 Scratch gage records, Building 3.6.

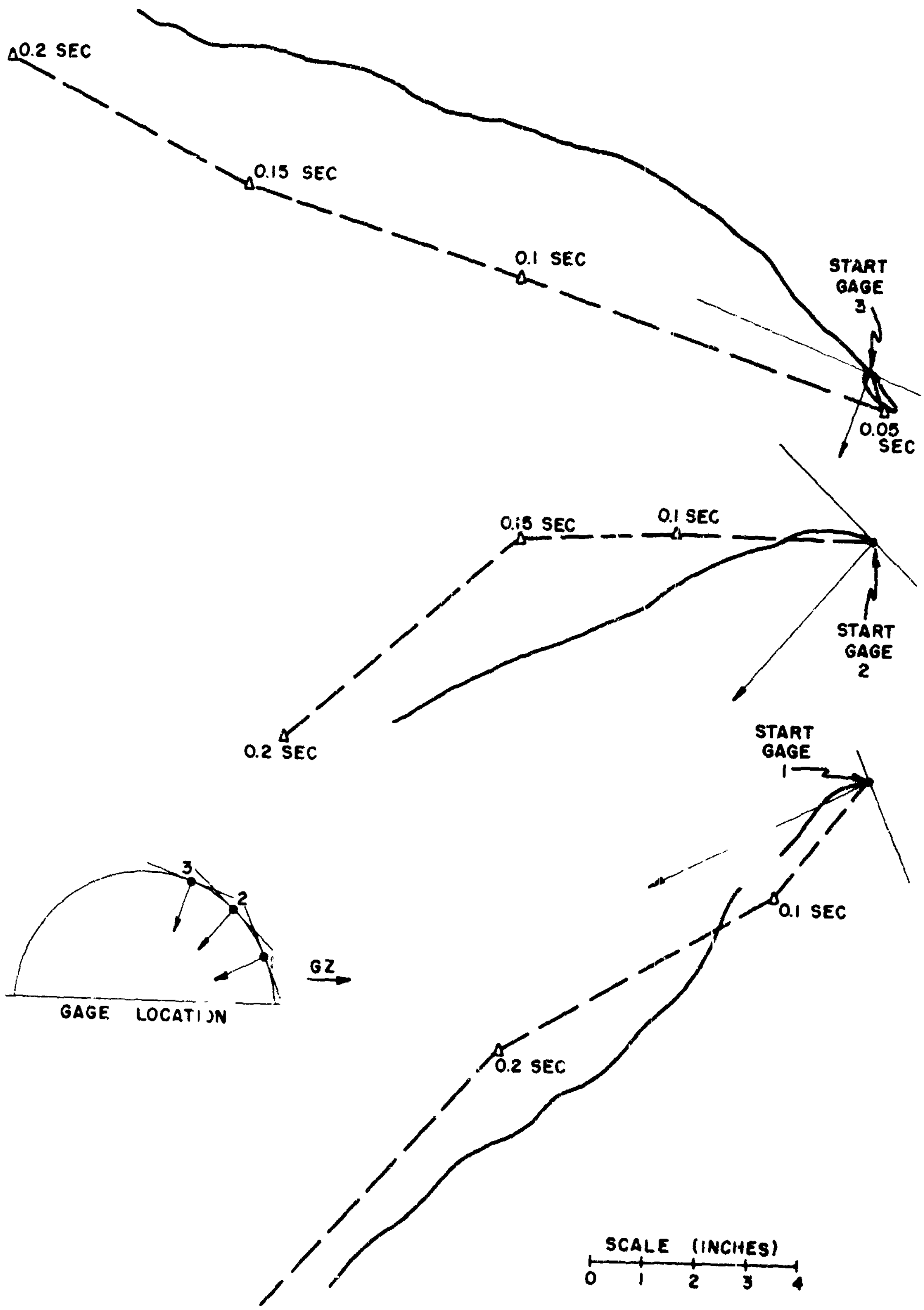
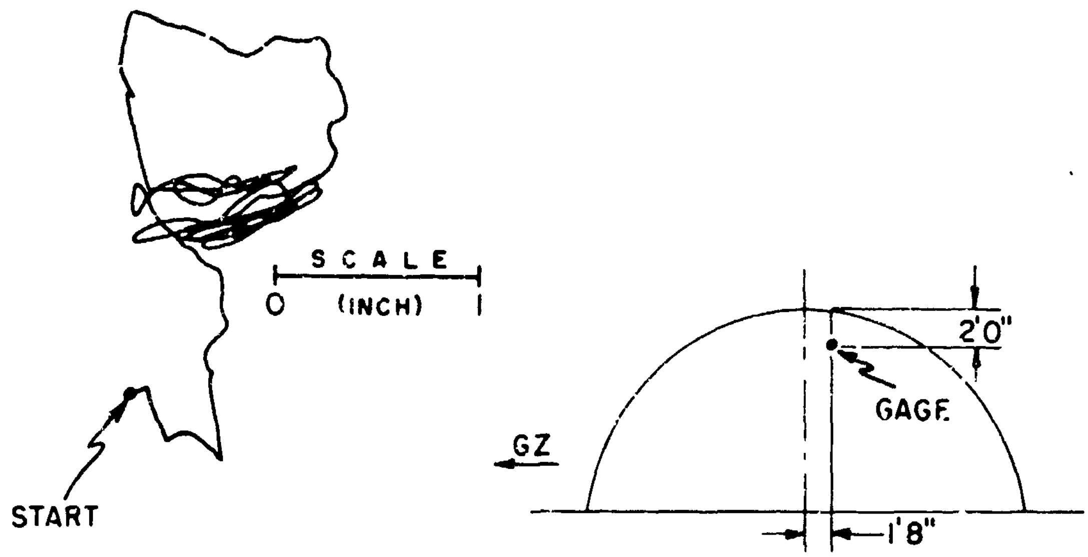
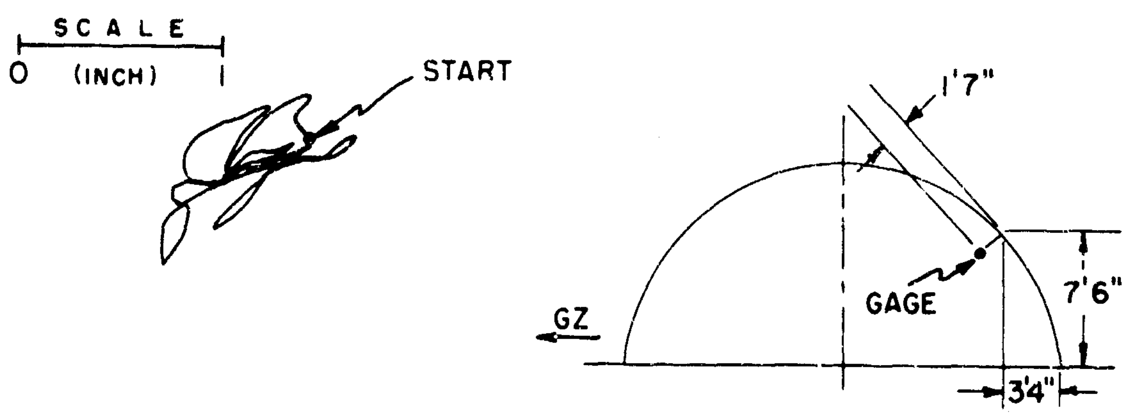


Figure 4.11 Scratch gage records, Building 3.6.



CROWN GAGE



LEEWARD GAGE

Figure 4.12 Scratch gage records, Building U-K 3.15.

Figures 4.10 and 4.11 indicated quite good correlation between the scratch gage records and the building movements specified in Figure 4.8.

4.2.2 Building U-K 3.15. The arch building similar to Building 3.6 which was tested as part of Project 3.15 on UPSHOT-KNOTHOLE was re-tested on Shot 12 of Operation TEAPOT. This building, located 2,300 feet from ground zero, was subjected to a maximum overpressure of 11 psi and a maximum dynamic pressure of 30 psi. The waveforms at this location were intermediate between those shown on Figure 4.13 and those shown on Figure 4.14. (For more complete information, see Reference 4.)

The only physical instrumentation in this structure was two scratch gages which had originally been used during the UPSHOT-KNOTHOLE operation and which were reactivated for Operation TEAPOT. These gage records, reproduced in Figure 4.12, show that the motion of the building was less than 2 inches and was, in fact, somewhat smaller than its motion on either Shot 9 or Shot 10 of Operation UPSHOT-KNOTHOLE.

4.2.3 Models. The three quarter-scale steel models of Building 3.6 were intended to sustain stresses identical to those of the prototype when the psi loading on the outside of the earth berm was identical to that of the prototype. Two of these models were subjected to greater dynamic pressures than the prototype and both failed. (The model at the same ground range as the prototype was deluged with water from the burst POL tank mentioned below, and hence was subjected to greater forces than was the prototype.) The third one was placed at 2,000 feet where the peak dynamic pressure was approximately one-third that on the

TABLE 4.1 PERFORMANCE OF MODELS

Model No.	Material	Ground Range (ft)	Max.* Dynamic Pressure (q) (psi)	Max.* Side-on Pressure (p) (psi)	p+0.25q	Movement of the Crown (in.) Permanent Movement	Maximum Excursion Up**	Down***
1	Steel	1400	200	35	85	Collapsed		
2	Steel	1500	180	30	75	Collapsed		
3	Steel	2000	64	19	35	5.4	4-1/8	4-3/16
4	Aluminum	2000	64	19	35	Collapsed		
5	Aluminum	2500	14	9	13	1.3	2-1/16	15/16
6	Aluminum	3000	2	8	9	0.6	5/8	9/16

* Blastline pressures at 3-foot height
** At 45°, up and away from GZ
*** At 45°, down and away from GZ

prototype; this model was not collapsed although it did sustain rather extensive crown deflection. There was no blastline station at 1,400 feet; by interpolation between measurements at 1,250 feet and 1,500 feet, the peak dynamic pressure at a 3-foot height at 1,400 feet was 200 psi. At 1,500 feet the peak dynamic pressure at a 3-foot height was 180 psi (Figure 4.1). At 2,000 feet it was 64 psi.

The three quarter-scale aluminum models were designed to have deflections scaled to those of the prototype if the models were subjected to external pressures one-quarter those of the prototype. Of these three models, the one at 2,000 feet was subjected to a peak dynamic pressure approximately 35 percent that of the prototype (Figure 4.13); this model collapsed as shown in Figure 4.19. The other two were at 2,500 feet and 3,000 feet, where the peak dynamic pressure was roughly 8 percent and 2 percent of the dynamic pressure applied to the prototype. Figures 4.14 and 4.15 show the pressures on the blast line at these distances. The performance of the models is summarized in Table 4.1 and Figure 4.16.

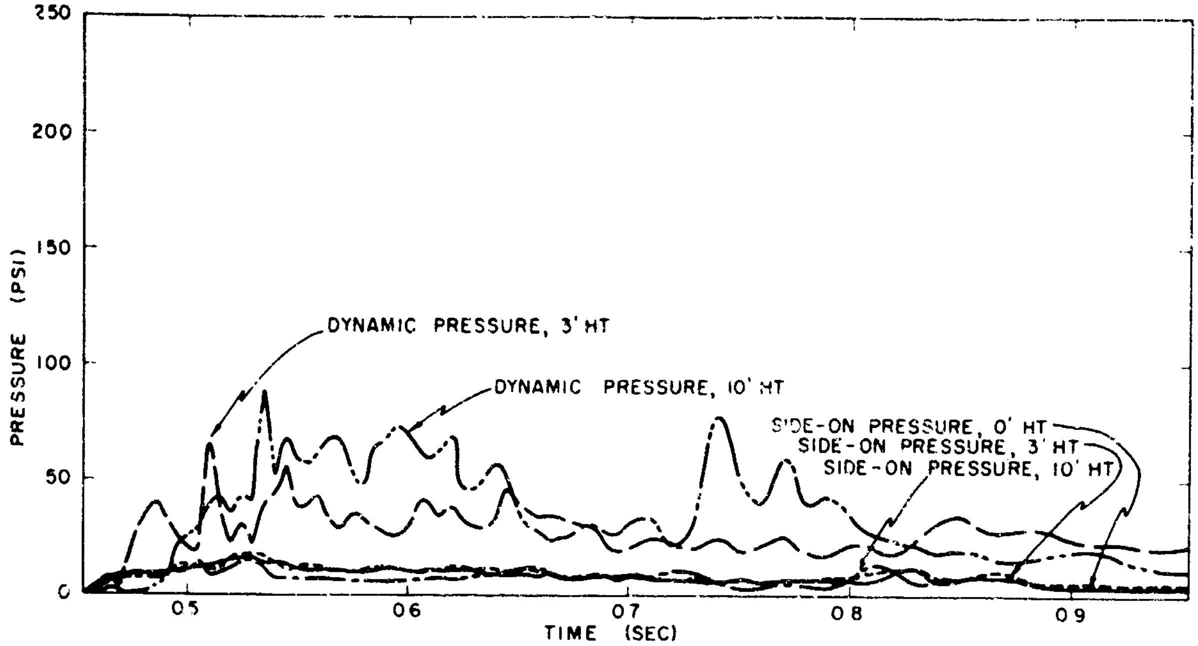


Figure 4.13 Pressure-time, desert line, 2,000 feet.

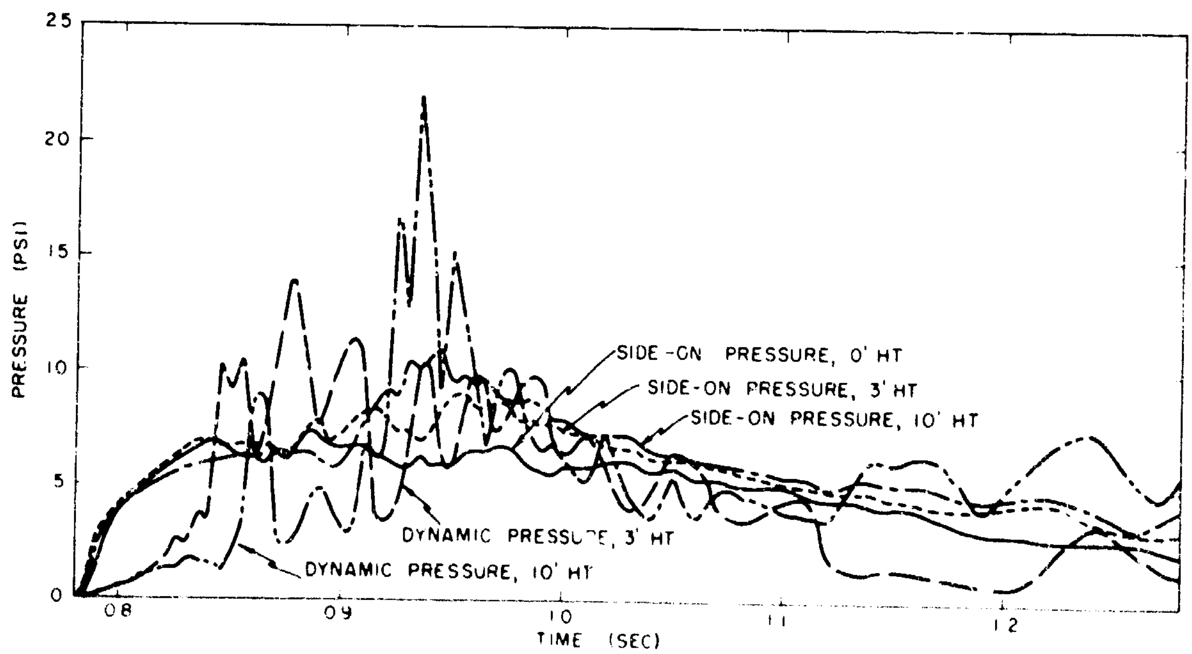


Figure 4.14 Pressure-time, desert line, 2,500 feet.

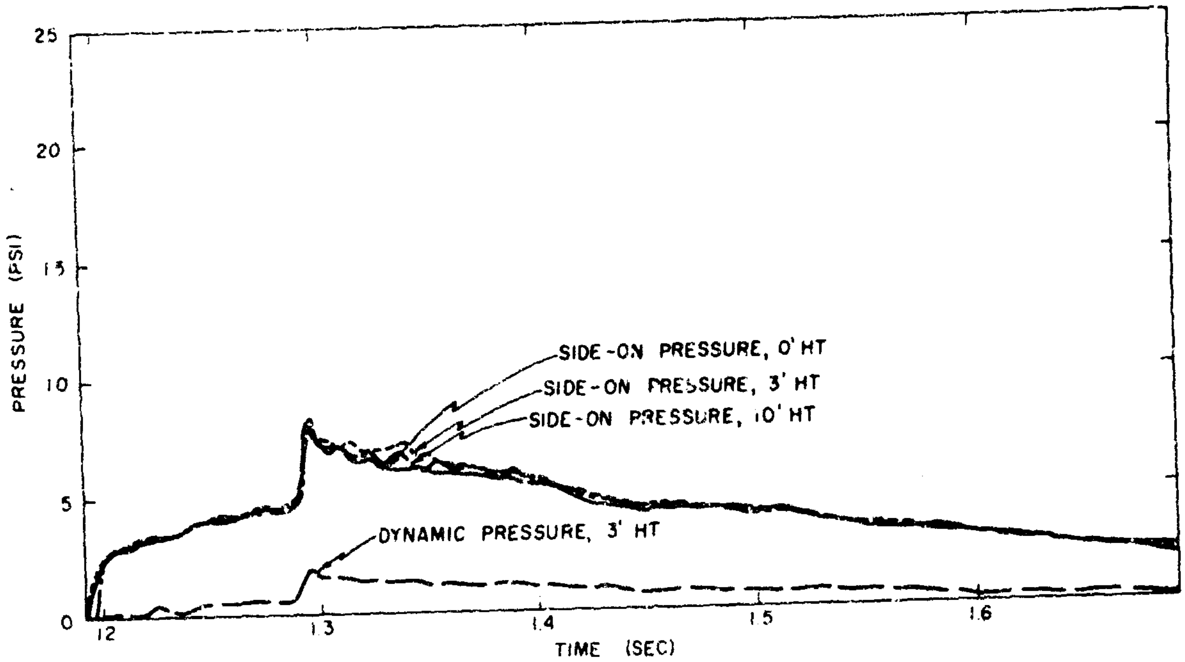


Figure 4.15 Pressure-time, desert line, 3,000 feet.

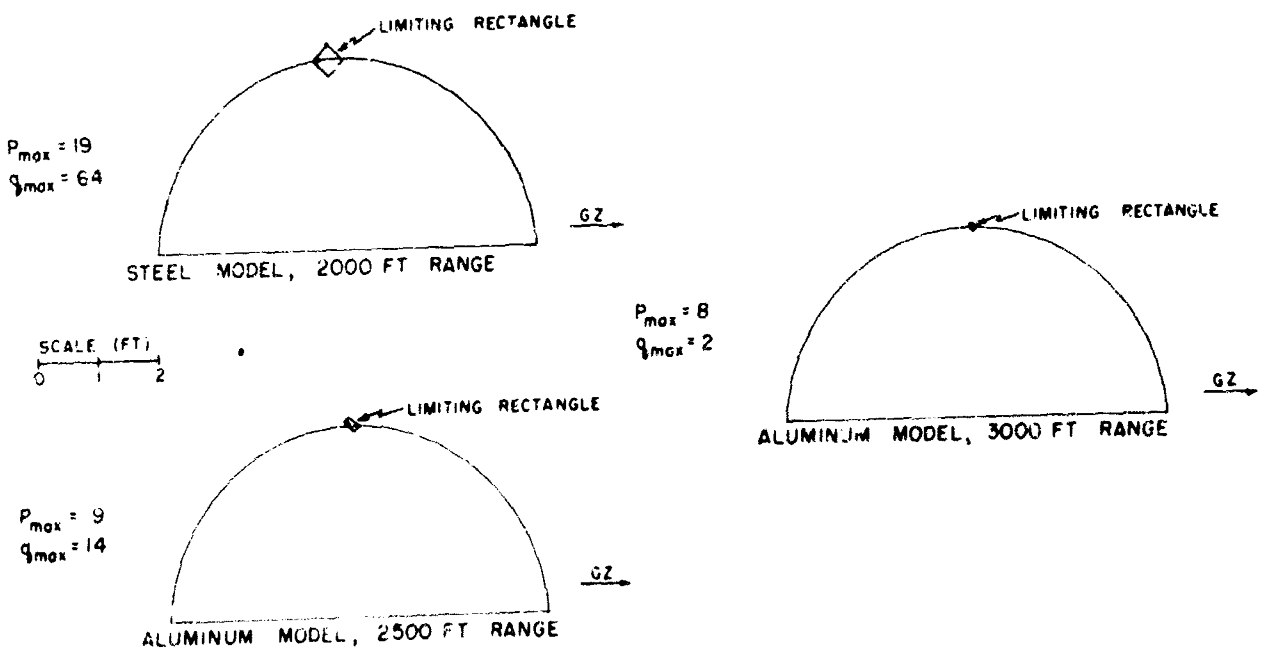


Figure 4.16 Model deflections. The crown touched all sides of the limiting rectangle and remained within it.

Each model was instrumented to permit determination of the maximum and permanent deflections of the crown along chords connecting the crown to the windward and leeward toes. Thus, in Figure 4.16, the maximum excursion of the crown is indicated by a curvilinear rectangle, and the dot within the rectangle represents the final location of the crown. The steel model at 1,400 feet was completely flattened and was scarcely recognizable after the shot. No photograph of it was taken. Figures 4.17 and 4.18 show the remainder of the model at 1,500 feet. In Figure 4.18, it is to be noted that the earth in the very near foreground was cracked from the drying of the water which poured over the area (and over the model) from the destroyed POL tank which had been placed somewhat nearer ground zero and whose final position was as indicated on the right-hand side of the photograph. In the background of this picture is the entrance to Building 3.6, where it can be noted that the entrance tunnel was partially crushed on the windward side.

In Figure 4.19 showing the two models at the 2,000-foot distance, it can be seen that the one in the foreground, the aluminum model, was destroyed; the farther one, the steel model, was still standing. The pile of earth around these models was considerably flattened and spread by the blast. This flattening and blowing away of the earth cover is even more apparent in Figure 4.20, which shows the model at 2,500 feet. In Figure 4.21, a photograph of the model at 3,000 feet, it is to be noted that the failure of the left-hand end of the model was caused by a jeep wheel which came to rest just to the left of the edge of the photograph. The model actually consisted of five corrugated sections, of which the jeep wheel completely crushed one section near the end. Since the instrumentation of the model was in the center section of the corrugated aluminum, the deflection measurement was intact and the model is considered to have successfully withstood the blast forces themselves.

4.3 RADIATION EFFECTS

On this project neither thermal radiation nor radiation from fallout were of significance, and the radiation of interest consisted of the initial gamma radiation and the initial neutron radiation. The radiation measurements reported below were all made by Project 2.7 and the report of that project, Reference 6, includes additional details of the instrumentation and procedures.

Two sets of radiation measuring instruments (film badges and neutron detectors) were placed inside Building 3.6. These two sets were located about 7 feet inside the entrance end wall; one location was 7 feet from the windward toe of the building, the other 7 feet from the leeward toe. The major group of instruments was at a 20-inch height, but a few measurements were made at a 38-inch height. The arrangement was such that the thickness of earth cover between the instrument array and the bomb was 15 feet in the case of the windward group of instruments and 12 feet for the leeward group. Because the building collapsed, only the leeward group of instruments was recovered promptly; the windward group was partially recovered some 24 hours later. It is possible that, as a second effect of the collapse, fallout material entered the build-

Figure 4.17 Model 2, 1,500 feet.

Figure 4.18 Model 2, 1,500 feet.

Figure 4.19 Models 3 and 4,
2,000 feet.

Figure 4.20 Model 5, 2,500 feet.

Figure 4.21 Model 6, 3,000 feet.

TABLE 4.2 RADIATION FLUX, TEAPOT SHOT 12

Some dosage figures are averages of several readings. For complete details see Reference 6, Tables 4.1 through 4.5. The flux values tabulated for fast and thermal neutrons are those determined by sulfur and gold detectors respectively. These detectors leave unmeasured all the neutrons having energies between 3 Mev and 0.4 ev. It is estimated that the total flux of fast neutrons outside the buildings, including both the measured and unmeasured range of energies, is of the order of four times the measured flux of fast neutrons.

Location	Height Above Floor (in.)	Gamma Flux (r)	Fast Neutron Flux (n/cm²)	Thermal Neutron Flux (n/cm²)
Building 3.6				
Inside, windward side	20 38	64 avg 700	4.14×10^{8}	4.51×10^{10}
Inside, leeward side	20 38 38	700 avg 87 540	3.79×10^{8}	4.70×10^{10}
Outside		71,200	1.91×10^{12}	9.87×10^{12}
Building U-K 3.15				
Inside, windward side	20 38	over 500 over 500	5.11×10^{9} 5.41×10^{9}	2.17×10^{11} 2.40×10^{11}
Inside, leeward side	20 38	900 920	1.58×10^{10} 1.76×10^{10}	3.09×10^{11} 3.06×10^{11}
Outside		14,400	3.4×10^{11}	1.44×10^{12}

ing and that the radiation from it increased to some extent the dosage measured inside the building.

Similar instruments were placed in equivalent locations in Building U-K 3.15. This structure was at a distance of 2,300 feet from ground zero and had originally been constructed with an earth berm roughly similar to that on Building 3.6. However, two modifications had been made since its first construction. These were: (1) that the cross tunnel of the TEE entrance had been removed; and (2) that the upper 3 feet of earth cover had been removed so that the steel arch of the building itself was uncovered at the crown of the arch.

In addition, it should be noted that this building and its earth berm had weathered for two years on Frenchman Flat. The radiation instrumentation was placed in this building at spots roughly corresponding to the instrument locations in Building 3.6. The configuration was such that the thickness of earth cover in the slant radius from the bomb to the instruments was also roughly the same as for Building 3.6. The basic data are presented in Table 4.2 and, later, in Figure 5.3.

Chapter 5

DISCUSSION

5.1 GENERAL SIGNIFICANCE

The physical results of this test (particularly the pressures measured on the windward slope compared with the free-field measurements, together with the fact that the building collapsed) demonstrate that a structure of this type and shape is, from a blast damage standpoint, primarily a drag-type or q-sensitive target rather than a p-sensitive target. Drag forces will be reduced by reducing the height of the earth berm until forces become zero for complete burial of the structure. Strength against both drag forces and p forces will be enhanced by increasing the gage of the corrugated steel, increasing the depth of corrugation, decreasing the span, stabilization of the soil used for cover, and widening the earth berm.

The protection against radiation afforded by the primary test structure, Building 3.6, was inadequate to assure survival, just as the building's resistance to blast was inadequate to assure survival under the test conditions.

It is believed that if this building had been placed 10 percent farther away from ground zero, it would have been operational after the test as far as blast is concerned. (The q forces would have been reduced some 17 percent.) However, the radiation at a 10 percent increased distance would still have been above the lethal dose and, in fact, the structure would have to be moved to a radius of some 2100 feet before the radiation dosage inside would have been reduced to the order of 200 rem.

5.2 BLAST EFFECTS

5.2.1 Building 3.6. The behavior of Building 3.6 was predicted in some detail before the blast on the basis of gross assumptions regarding both the blast-induced forces and the response of the building and earth berm. Since the maximum dynamic pressures exceed the estimated value by something more than 60 percent, it occasioned no surprise that the building deflections were vastly larger than the estimated values. The maximum predicted deflection of the arch barrel was 1 foot. Figure 5.1 shows the predicted building shape as well as the actual final shape determined by measurement. Since the prediction of deflections in the neighborhood of the yield point is necessarily fraught with considerable uncertainty, the disparity in the actual, very large deflections

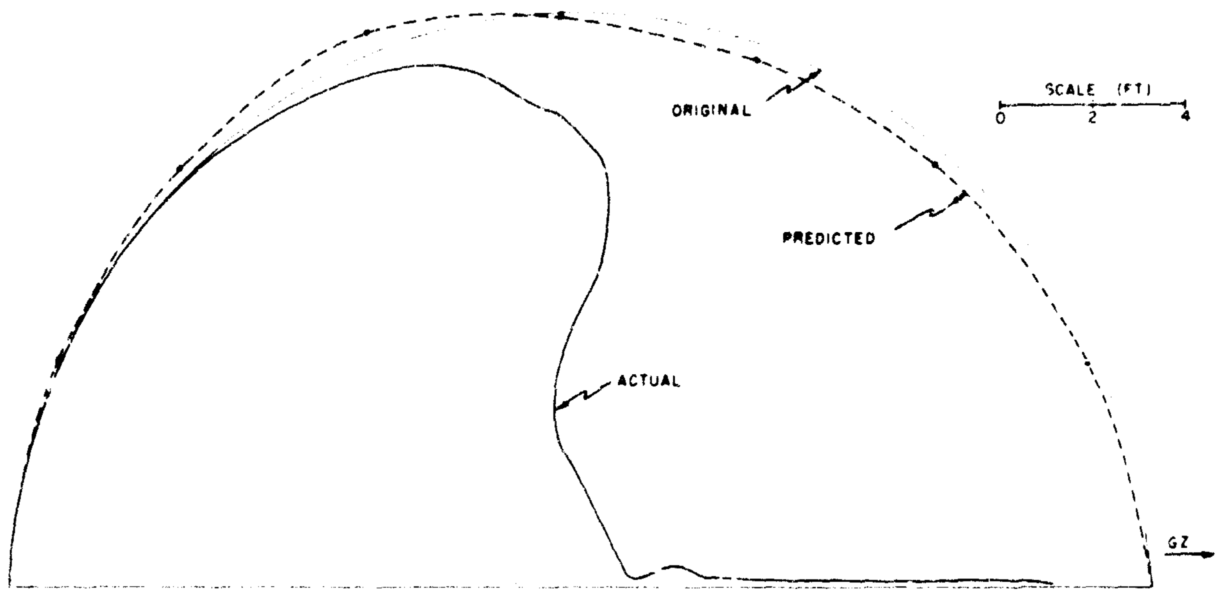


Figure 5.1 Predicted and actual final profiles, Building 3.6.

involved in the collapse compared to the relatively modest values predicted warrants no apology.

The deflections of Building 3.6 at various times are shown again in Figure 5.2, where the pressures on the earth berm at these same times are also shown. The pressure wave from the shot arrived at this building approximately 0.3 second after zero time and the times shown in this figure are described in intervals after arrival of the blast wave. For ready reference, the free-field pressures (both dynamic and side-on overpressure for the same times) are shown on this figure. It can be noted from the figure that, at a time between 0.2 and 0.3 second after arrival of the blast wave, the pressure on the outside of the earth berm had been reduced to a figure well within the capabilities of the undistorted building. The fact that the building continued its movement until it collapsed simply indicates that the load impulse prior to this time was sufficient to produce an ultimate deflection so large that the strength of the steel barrel was inadequate to carry even the static load of the earth cover. The severe dissymmetry of the load on the two sides of the earth berm is also clearly brought out in this figure.

One further thing is worthy of note on Figure 5.2; this is the comparison of the profile of the earth berm before and after the shot. In addition to the depression of the top of the berm on the windward side, which obviously was a result of the collapse of the windward half of the building, it can be seen that, on both sides, the toe of the earth berm widened. This situation is duplicated on the models, as can be seen in Figures 4.17 through 4.21.

To assist in the preshot predictions it had been assumed that the pressure on the windward slope of the earth berm would be p + 0.5 q and that the pressure on the leeward slope would be p - 0.7 q. It was of

interest to determine corresponding figures from the actual data after the shot.

In the attempt to accomplish this it was found at once that the wave forms of the pressure records, both p and q and those on the earth berm, were so jagged and so divergent from each other that no point-to-point method was useful. The pressure readings were therefore averaged for the 0.2 second following shock arrival and these average values were then compared. The result is that on the windward slope the average pressure was p + 0.25 q. The instrumentation on the top of the earth berm was not satisfactory because two of the three gages were seriously displaced and their records lost; hence for the top of the earth berm the preshot assumption is as good as can be made, namely that the pressure on the top of the earth berm was equal to p. On the leeward slope the records in Figure 4.2 indicate a sharp peak at the initial arrival and thereafter values always very close to zero. This first peak has been ignored and the value zero was assumed to be the average for the actual pressure on the leeward slope. On this basis the pressure on the leeward slope was p - 0.1 q. For the purpose of assisting in the design of earth-covered structures under other circumstances, it is probably safer simply to assume that the pressure on the leeward slope will be zero, if q is large (say, above 50 psi).

5.2.2 Building U-K 3.15. The presumptions stated in the previous section were used to attempt to specify the situation at Building U-K 3.15 during Shots 9 and 10 of Operation UPSHOT-KNOTHOLE. The results are shown in Table 5.1. It is apparent from Table 5.1 that the dissymmetry of loading on this building was trivial on U-K 9, somewhat more severe on U-K 10, and still more severe on TEAPOT 12, but that it was never of the same order of magnitude as the dissymmetry of loading on Building 3.6.

The relatively small deflections of Building U-K 3.15 during TEAPOT Shot 12, as indicated by the scratch gage records in Figure 4.12, are of particular interest because these deflections are somewhat less than those observed on UPSHOT-KNOTHOLE Shots 9 and 10. In the light of dynamic pressure measurements made on TEAPOT, it has been possible to make somewhat better estimates of the dynamic pressures existing on the UPSHOT-KNOTHOLE series. The peak dynamic pressures at the location of Building U-K 3.15 (2,300 feet from ground zero) were: on TEAPOT Shot 12, 30 psi; on UPSHOT-KNOTHOLE Shot 9, 4 psi; and on UPSHOT-KNOTHOLE Shot 10, 7 psi. Between U-K Shots 9 and 10 the earth cover on the crown of this building was removed, so that the earth berm was lower than that of Building 3.6 on TEAPOT. In addition, the U-K 3.15 earth berm had, of course, been compacted by the previous shots and had weathered in the Frenchman Flat environment for some 24 months.

5.2.3 Models. The addition of models to this test program was based on the probability that structures of the type under study fail when they become so distorted by the unbalanced q forces that they are no longer able to support the earth load and surcharge. Therefore, in devising an economical system of model instrumentation it was decided to make the primary measurement for maximum displacement at the crown, hoping for correlation with either the dynamic displacement gages or the scratch gage records in Building 3.6.

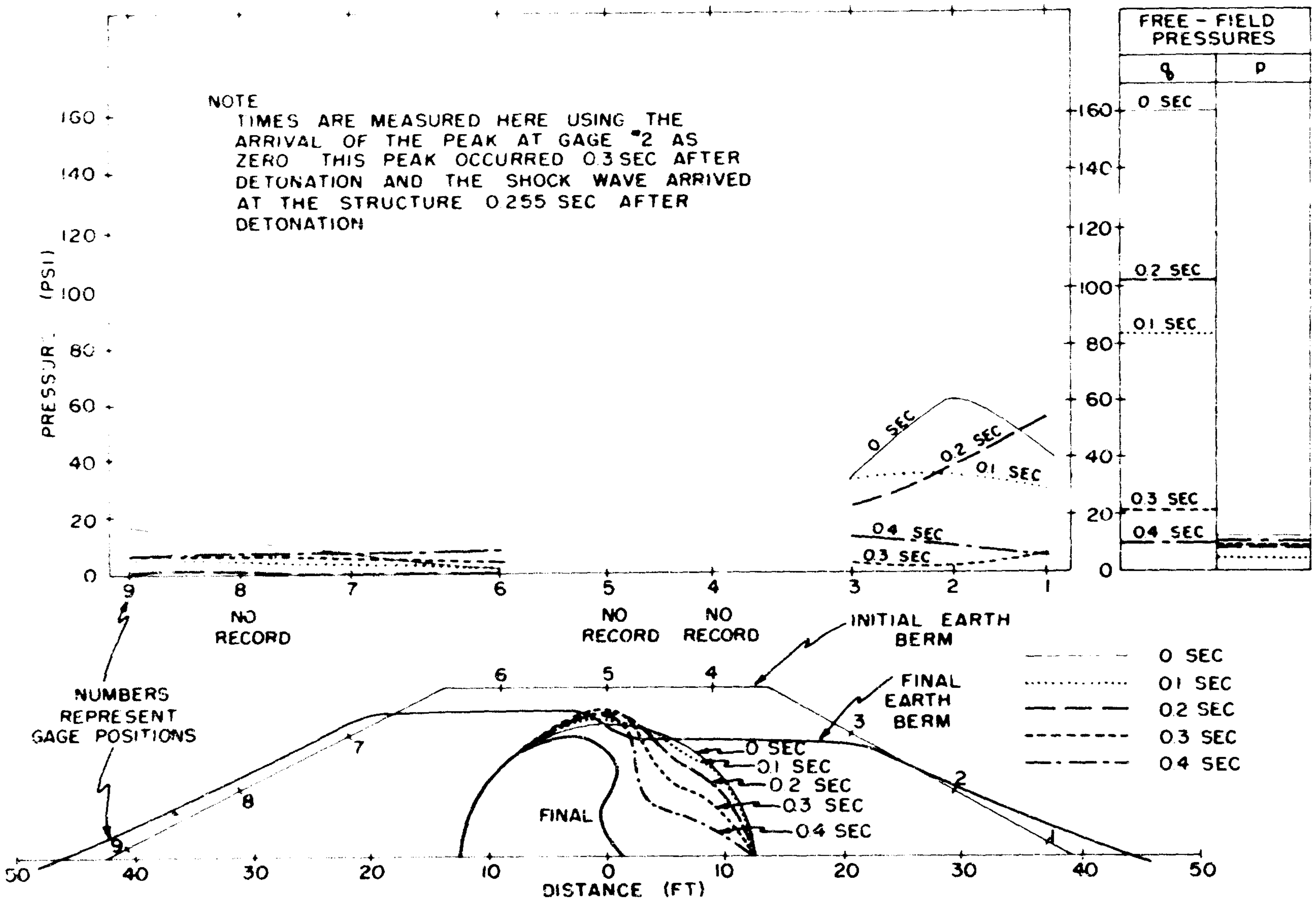


Figure 5.2 The pressures against the earth berm, Building 3.6, at various times compared to the free-field pressures and the resultant deflections of the building.

The models were designed with the intent stated in Section 1.2, namely that the steel models should fail under the same psi loading as the prototype and should have one-quarter the absolute deflection, and that the aluminum models should fail at one-quarter the psi loading and should have a failure deflection one-quarter that of the prototype. Perfect modeling materials and shapes are not available however, and the models were therefore actually constructed with the properties indicated in Table 2.1. For models actually used, the following relative

TABLE 5.1 PRESSURE VALUES ON UPSHOT-KNOTHOLE AND TEAPOT

Quantity	U-K 9	U-K 10	TEAPOT 12
p peak	10.8	8.1	11
p avg*	7	6	8
q peak	4 est.	7 est.	30
q avg*	3 est.	5 est.	15
p avg + 0.25 q avg	7.75**	7.25**	11.75
p avg - 0.1 q avg	6.7**	5.5**	6.5

* Averaged over the 200 msec after arrival.

** It is of interest to compare these estimated values of pressure on the front and back faces of an obstruction with some of the measured values on U-K Shots 9 and 10. The value 7.75 estimated here for a windward-face pressure can be compared with the value 5 psi as measured on the windward side of the crown of the earth-covered structure U-K 3.13a at Gage P1, as reported on Page 139 of Reference 1. (Note that both the figures in the table above and the figures taken from the previous report are values averaged from the first 200 msec.) The value of 6.7 in the table above can be compared to the value of 4.5 psi on Gage P2 on the leeward side of the earth berm of U-K 3.13a. On Shot 10, Structure 3.13a was uncovered and additional gages on surfaces of the building were available for measuring air pressure. Comparisons can be made with gage records P4 and P6 on Page 142 of Reference 1. In the table above the figure 7.25 psi is compared with 5 psi measured and the value 5.5 estimated in the table above is compared with 4 psi measured. These comparisons lead to a modest confidence in the validity of the empirical equation.

deflections should result from a particular psi value of loading: prototype, 1.00 inch; aluminum model, 0.57 inch; and steel model, 0.17 inch. (If perfect materials and shapes had been available, these values would have been 1.00 inch and 0.25 inch for the aluminum and steel models respectively.)

It is of interest to correlate the deflection of the two surviving aluminum models with that of the one surviving steel model. The

computed deflections tabulated below permit comparison of the hypothesis that deflection is proportional to q with the hypothesis that deflection is proportional to (p + 0.25 q). It is clear that the model results are more nearly in agreement with the first hypothesis.

The steel model, No. 3, sustained a deflection of 4.12 inches as a result of p and q values listed in Table 4.1. In Table 5.2 below, the computed deflection of aluminum model No. 5 is determined by multiplying the deflection of Model 3 (4.12 inches) by the ratio of the loading on the two models (14 psi/64 psi) and by the ratio of the relative deflections expected of the two models under identical loadings (0.57 inches/ 0.17 inches). The deflection computed for model No. 5 in this manner is 3.0 inches.

One conclusion which can be drawn from the preceding discussion is that the earth did not act with the metal in resisting displacement of the crown of the model. That is, at three different locations displacement varies directly as q and inversely as EI of the metal. (Even if this be so, the earth is not "worthless"; it greatly modifies the applied loads and also enables the building to resist large p forces.) It would be unjustified to extend this inferred conclusion to the prototype, first because the earth on the models was not compacted, and second, because considerable earth was blown off the top of the models. It might be for example, that the top 6 inches of earth are blown away, or perhaps transported 6 feet to leeward on either model or prototype. This would have little effect on the prototype but a pronounced effect on the model. Should similar experiments be conducted in the future, it is recommended that the earth over the models be appropriately moistened and compacted, and that the surface be stabilized.

TABLE 5.2 CALCULATED MODEL DEFLECTIONS

Model No.	q (psi)	p + 0.25 q (psi)	Measured Deflection (in.)	Predicted Deflections (in.) (q)	(p + 0.25 q)
3 - steel	64	35	4.12	4.12	4.12
5 - alum.	14	13	2.1	3.0	5.1
6 - alum.	2	9	0.6	0.4	3.5

If we assume model similitude, the model results may be used to bracket the region of failure for the prototype as shown in Table 5.3. Unfortunately, the bracketing from survival at 64 psi to failure at 130 psi is too wide to permit any specific conclusions as to the accuracy of the model analogy.

When earth-covered models were tested at SRI in 1954 under unbalanced static loads, all failed before a crown deflection of 1 inch was reached. (The SRI models were constructed of 0.032 inch aluminum while on TEAPOT the aluminum models were 0.040 inch, and the steel models were 0.050 inch; but there is no reason to believe the configuration

at failure would be significantly different for a steel model, although the loads would be larger. The test results are reported in Reference 1, Supplement D.) The steel model at 2,000 feet showed a deflection of 4.12 inches without failure. It may be definitely stated, therefore, that this model can resist a distortion under blast loading which is more than four times the distortion associated with failure under a static load of similar direction. This may well be one of the most useful conclusions which can be drawn from the model work, for it appears fully applicable to the prototype, which, because of its greater period, should be even less affected by transient loads.

On run No. 10 of the SRI series of static tests, 4.5 psi unbalanced (i.e., 6.5 psi - 2 psi) was the failure load. If the conclusions stated above is valid and if deflection is proportional to load, then this model should have withstood an impulsive load of 4 x 4.5, or 18 psi. As shown in Section 5.2.1, the unbalanced load can be approximated by

TABLE 5.3 MEASURED MODEL DEFLECTIONS

Model No.	q (psi)	Measured Deflection (in.)	Model Ratio Pressure	Model Ratio Deflection	Equivalent Values for Prototype q (psi)	Equivalent Values for Prototype Deflection (in.)
1 - steel	200	Collapsed	1	1/0.17	200	Collapsed
2 - steel	180	Collapsed	1	1/0.17	180	Collapsed
3 - steel	64	4.12	1	1/0.17	64	24
4 - alum.	64	Collapsed	4	4/0.57	256	Collapsed
5 - alum.	14	2.1	4	4/0.57	56	15
6 - alum.	2	0.625	4	4/0.57	8	4.4

(p + 0.25 q) - (p - 0.1 q) = 0.35 q. The aluminum field models withstood an impulsive load of 14 psi and failed at an impulsive load of 64 psi; the equivalent static unbalanced loads would be 4.5 psi and 22 psi.

In future model tests, a further check could be made on the ratio of static to dynamic capacity by running a static test on a steel model which did stand 22 psi. In any event, for structures of this configuration, static tests can be used to give a rough idea of their probable blast resistance, using a ratio of dynamic resistance to static resistance somewhere in the range between 4 and 6. Such tests should be quite useful in determining the range at which future blast experiments should be set to gain the most useful results.

5.3 RADIATION

Thermal radiation is ordinarily a matter of no concern in the design of shelters primarily because earth cover is necessary for other reasons and it is highly resistant, in a bulk sense, to damage by thermal radiation.

A shelter designer must, in general, be concerned with radiation from two sources. The first is the initial nuclear radiation from the shot and the second is the radiation from radioactive fallout. In regard to radiation from fallout, gamma rays of relatively low energy are the major factor; beta and alpha radiation may be of some long time significance although they are not likely to have acute aspects. In this experiment no attention was paid to the fallout radiation.

In regard to initial radiation, gamma rays are of particular interest to the shelter designer but neutrons are also important. Both types of radiation are subject to the same broad laws, which are that radiation from a point will be decreased in intensity first by an inverse square law, second by attenuation (absorption and scattering) in the air which it traverses, and third by similar (but more severe) attenuation in more solid material, such as the earth cover used around the shelter. In general, the attenuation of radiation is an exponential function of distance; thus to a first approximation one can say that the total dosage is:

$$r = k \frac{1}{d^2} e^{d/a} e^{t/b} \qquad (5.1)$$

Where:
r = total dosage
k = a constant depending on yield and on design of the bomb
d = distance from bomb
a = characteristic attenuation in air
t = thickness of soil
b = characteristic attenuation in soil
e = natural logarithmic base

Gamma rays follow these laws rather precisely. Characteristic distances are that the gamma dosage would be decreased by a factor of 10 in approximately each 2,500 feet in air and in approximately each 2 feet in soil. Similarly, fast neutrons are attenuated by a factor of 10 in approximately 1,500 feet of air or in approximately 2 feet of earth.

The situation for thermal neutrons from an atomic explosion is somewhat different for two reasons. First, their number is augmented by the fast neutrons which are moderated in their passage through the intervening air or soil, so that, in practice, the flux of slow neutrons may fall off more nearly as the inverse first power of distance than as the square power. Second, while for a considerable distance (several thousand feet) from the shot, gamma rays and fast neutrons for the most part have a velocity directly away from their point of origin, thermal neutrons are so extremely affected by their many collisions that they quickly become randomized in direction. Hence they appear to an observer to come from a diffuse source, or cloud, rather than from a point source.

The results of the radiation measurements on TEAPOT Shot 12 are shown in Figure 5.3. In this figure the buildings sketched on the right-hand side are Building 3.6 and those on the left-hand side are Building U-K 3.15. In each case the main arrow gives the straightline direction from the center of the building to the top of the shot tower. The upper pair of figures give the situation for gamma radiation, in which the numbers are the measured total dose in roentgens. In the middle pair of figures the fast neutron flux measurements are similarly displayed,

and in the bottom pair those for thermal neutrons.

Several important physical differences between these two shelters are apparent. These are: (1) Building U-K 3.15 had no earth cover above the crown of the building; (2) total thickness of earth cover in the straight line toward the shot point was somewhat less in Building U-K 3.15; (3) the total water content of the earth cover in Building U-K 3.15 was considerably less than that for Building 3.6 (this is because the U-K 3.15 cover was put on in 1953 and had weathered and dried out for two years, whereas the cover was placed on Building 3.6 approximately one month before shot time in 1955 and was thoroughly dampened during placement); and (4) Building 3.6 collapsed, while Building U-K 3.15 remained standing.

5.3.1 Gamma Radiation. The measurements of gamma radiation shown in Figure 5.3 are of interest in several respects. The fact that the shielding factors (the ratio of flux measured inside the building to flux measured outside) for Building 3.6 (approximately 1/100) and that for Building U-K 3.15 (approximately 1/15) show much less attenuation than would be expected for the 10-15 feet of earth in the straight line path from the detectors to the bomb, leads to the conclusion that most of the gamma radiation inside the buildings came as a result of gammas scattered in the relatively thin earth cover close to the crown. The gross difference in the readings on the windward side inside Building 3.6, namely the single film badge measurement of 700 r at the 38-inch height compared to the average of 3 film badges and one anhydrous chloroform dosimeter at a height 20 inches, which are grouped closely around the average of 64 r, represents an anomaly for which no reasonable explanation has been found. The single measurement of 700 r is somewhat more consistent with the other measurements in Building 3.6 and U-K 3.15 but it appears necessary in an objective sense to place more reliance on four consistent readings than on one isolated film badge. No hypothesis has been found by which the gamma radiation at these two locations only 18 inches apart and separated by air could differ by a factor larger than 10. These badges and dosimeter were found under the collapsed half of the building and they were recovered some 24 hours later than the similar badges and dosimeters on the other side of the building.

The deduction that most of the gammas entered by penetration and scattering near the crown is further confirmed by the difference in the shielding factors of the two buildings. Building 3.6 carried 3 feet of earth cover near the crown and had a shielding factor of 1/100, whereas Building U-K 3.15 carried no earth cover at the crown and had a shielding factor of 1/15.

It is of interest to compare the gamma radiation results of Buildings 3.6 and U-K 3.15 on Shot 12 of TEAPOT with the results of gamma measurements on U-K Shot 9 as reported in Reference 7. Building U-K 3.15 during Shot 9 was approximately similar to Building 3.6 on TEAPOT 12 in that 3 feet of earth covered the crown of the building and approximately 15 feet of earth cover lay in the direct line between the center of the building and the tower. The attenuation factor for Building U-K 3.15 on UPSHOT-KNOTHOLE 9, as indicated in Reference 7, was of the order of

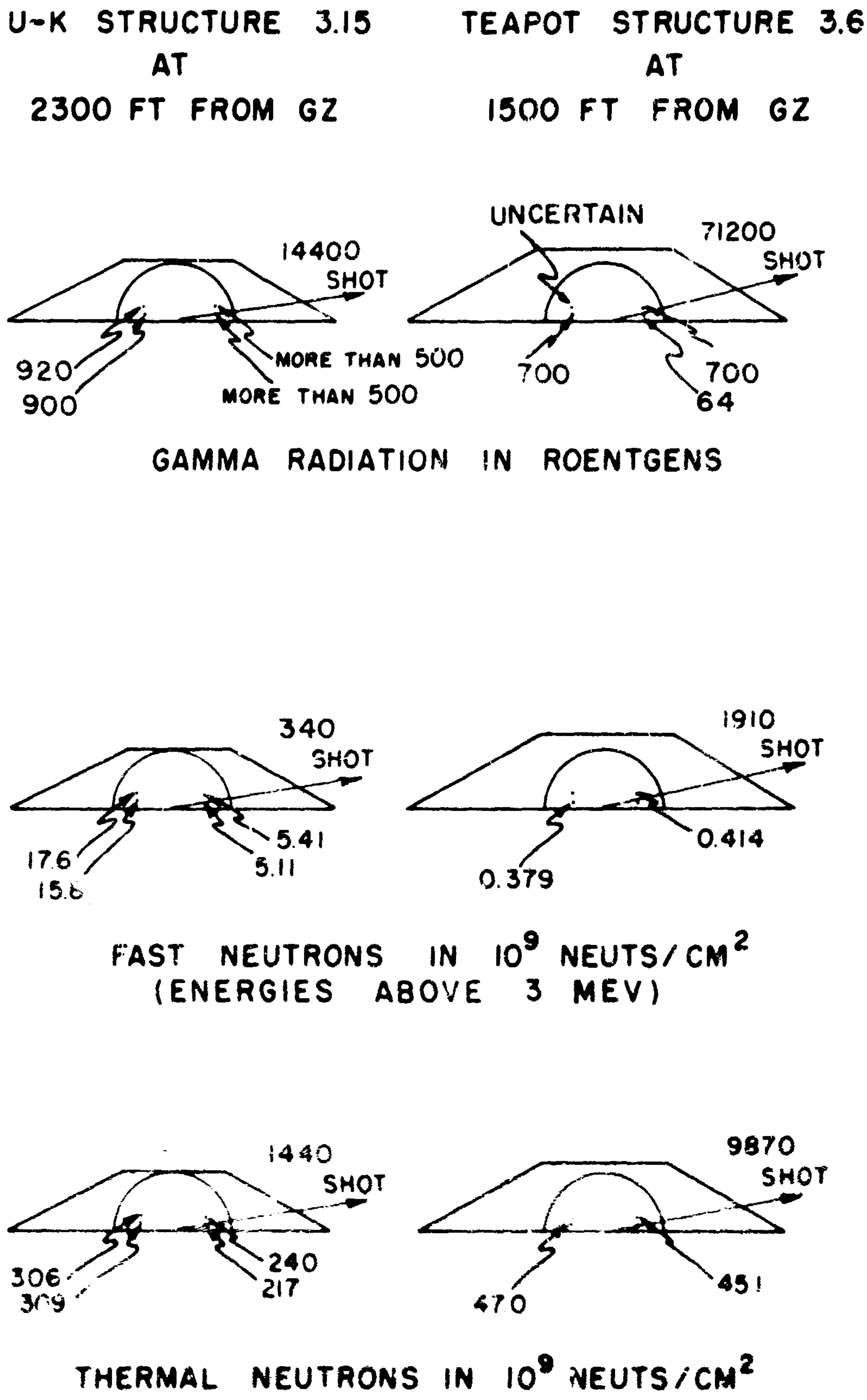


Figure 5.3 Measured radiation flux at Buildings U-K 3.15 and TEAPOT 3.6 on TEAPOT Shot 12.

1/200, whereas on TEAPOT 12 the attenuation factor was about 1/100. Furthermore, while the gamma intensity inside Building 3.6 appears to be roughly independent of the location of the detection instruments, the measurements in Building U-K 3.15 on Shot U-K 9 had a rather large scatter. Thus the current conclusion that the major gamma dosage inside the building came from gammas scattered in the earth cover above the crown represents a sharp change from the conclusion drawn from U-K Shot 9 to the effect that most of the gamma radiation came in a direct line from the bomb.

The biological effectiveness of gamma rays is about equal to that of the hard x-rays used as a standard; the RBE (defined in Section 5.3.3) is between 0.8 and 1.0. Assuming it to be 1.0, the biologically effective gamma dose is the same as the measured flux in roentgens. The gammas dosage of 700-900 r inside the buildings exceeds a lethal dose regardless of any current uncertainty in the value of the LD-50 dose.

5.3.2 Neutron Flux Measurements. The fast neutron flux measurements presented in the second part of Figure 5.3 are for only a portion of the total fast neutron energy spectrum, i.e., that part from 3 to 10 Mev. It is estimated on the basis of the distribution of fission neutrons versus energy that if lower energy neutrons had also been measured, the total values for fast neutrons would be about four times as large outside the structure, and about three times as large inside the structure. The difference in the ratios represents the assumption that a portion of the intermediate energy neutrons were converted to thermal neutrons in passing through the earth cover.

It is to be noted that on the two sides of the interior of Building 3.6, the fast neutron flux measurements were approximately the same, whereas the values on the far side of the interior of Building U-K 3.15 were three or four times larger than those on the near side. This fact indicates that while the neutrons may be thought of as arriving from a somewhat diffuse source, they still retained some evidence that they originated at the shot point. It is also noteworthy that the fast neutron flux measurements inside Building U-K 3.15 were much larger than in Building 3.6, despite the fact that the total neutron flux outside the former was much smaller than the flux outside the latter. The relative shielding afforded by the two structures would be expected to differ, both because there was no earth above the crown of U-K 3.15 and also because there was a much smaller water content in the earth cover of that building. Assuming that the measured flux represents one-fourth the total outside the building and one-third the total inside the building, the attenuation factor for fast neutrons is about 1/6700 for Building 3.6, but only 1/30 for U-K 3.15. The more extensive earth cover of Building 3.6 evidently accomplished a greater reduction in fast neutron flux than in gamma radiation.

In regard to thermal neutrons, the close equivalence of readings on the two sides within both buildings indicates that the thermal neutrons arriving within the buildings came from a very diffuse source. In fact, many of them may have come from moderation of fast neutrons within the earth cover itself. The attenuation of thermal neutrons was about 1/200 for Building 3.6 and 1/5 for Building U-K 3.15.

5.3.3 Neutron Dosage. Before concluding the discussion of the radiation measurements, one should consider the relative importance of the neutron dosage compared to the gamma dosage, from the standpoint of biological damage.

The units used in radiation measurement may be defined either on a physical basis or on the basis of biological damage. The roentgen (r) is defined in terms of the amount of ionization produced in air by X-radiation. To provide for measurement of ionization caused by other types of radiation, the roentgen-equivalent-physical (rep) was established, and defined so that one rep of any type of radiation provided the same amount of ionization in air. However, different types of radiation have different degrees of biological effectiveness, even when the same quantity of ionization energy is produced. Hence, the relative biological effectiveness (RBE) was defined to compare the biological effectiveness of other radiation to that of gamma radiation. The rem, or roentgen-equivalent-man, can then be defined as (no. of rem) - (no. of rep) x RBE. Thus 1 rem of any type or radiation will have the same biological effect. (This discussion of units is condensed from Reference 8, which contains a more complete discussion of them.)

The International Commission on Radiological Protection suggests an RBE for neutrons of 10 (Reference 9). This value is intentionally conservative, since it is used in establishing permissible dosages for occupational exposures. In Reference 8, Chilton, after surveying various experiments, describes a proton RBE value of 10 as "very conservative", a value of 5 as "mildly conservative", and a value of 2 as "most probable." It is the opinion of the author (of WT-1128) that RBE values for neutrons can be considered to be essentially the same as RBE values for protons and hence it is believed that Cdr. Chilton's conclusions regarding proton RBE's can, for the purpose of this report, be translated directly into values of neutron RBE's. Confirming this opinion, Harris (Reference 10) uses an RBE of 1.7 for neutrons, which corresponds to Chilton's value of 2 as the most probable RBE for protons. It is beyond the scope of this project to evaluate the uncertainties in the values of RBE for neutrons, and they are not significant in any of the conclusions; at the recommendation of AFSWP, Harris' neutron RBE of 1.7 is the value used in this report.

Table 5.4 and Figure 5.4 present a summary of the Project 3.6 neutron dosage calculations. These values are of course only approximate, since the estimation of neutron flux in the intermediate energy ranges may not be accurate. However, it is evident that the neutron dosage in Building 3.6 is negligible compared with the gamma dosage in that building of over 700 rem; while in U-K 3.15, the sizable neutron dosage of 300 rem is only a third the gamma dosage of over 900 rem. In these structures, therefore, the gamma dosage is the important quantity to consider from the standpoint of biological damage.

5.4 SHOCK-TUBE MEASUREMENTS

Shock-tube measurements were made by the BRL on a trapezoidal, three-dimensional model of Building 3.6 and its earth cover as shown in Table 5.5. These shocks correspond to Mach numbers in the range of 0.5.

It was decided before the field test to extrapolate these results into the region of p = 20 psi and q = 50 psi, which corresponds to a Mach number of about 1.5. After the test it was decided to compare the shock-tube results with the field-test results in the region p = 10 psi and q = 150 psi, which corresponds to a Mach number of about 3.

In attempting the extrapolation of the shock-tube data from the relatively modest shock strengths, particularly extrapolating q values to the quite large values expected and encountered in the field, it was decided that the parameter q/p might serve a useful purpose. Following this procedure the value of q/p was plotted against the shock strength p/p_0 for each one of the nine gage positions and for each of the four shock strengths used by BRL. To simply the procedure for extrapolation and predictions so that it would remain within reasonable bounds of complexity, the value of q/p used was the average after the transients had died away. These data, when plotted on linear paper were found to fall quite close to a straight line for each instrument location. The parametric equation of each line was therefore easily determined and when translated to terms of overpressures and dynamic

TABLE 5.4 NEUTRON AND GAMMA DOSAGES

	Building U-K 3.15	Building 3.6
Gamma rays:		
Dose outside (rem)	14,400	71,200
Dose inside (rem)	920	700
Shielding ratio	1/15	1/100
Measured thermal neutrons:		
Flux outside (n/cm^2)	$1,440 \times 10^9$	$9,870 \times 10^9$
Flux inside (n/cm^2)	300×10^9	46×10^9
1 rep = 2.9×10^{10} n/cm^2		
RBE = 1.7		
1 rem = 1.7×10^{10} n/cm^2		
Dose outside (rem)	85	580
Dose inside (rem)	17	2.8
Measured fast neutrons (3-10 Mev):		
Flux outside (n/cm^2)	340×10^9	$1,910 \times 10^9$
Flux inside (n/cm^2)	15×10^9	0.4×10^9
Estimated total fast neutrons:*		
Flux outside (n/cm^2)	$1,360 \times 10^9$	$8,000 \times 10^9$
Flux inside (n/cm^2)	45×10^9	1.2×10^9
1 rep = 2.5×10^8 n/cm^2		
RBE = 1.7		
1 rem = 1.5×10^8 n/cm^2		
Dose outside (rem)	9,000	53,000
Dose inside (rem)	300	8
Estimated total neutrons (thermal plus fast):		
Dose outside (rem)	9,085	53,580
Dose inside (rem)	317	10.8
Shielding ratio	1/30	1/5000

* It is estimated that outside the building the measured fast neutron flux is only one-fourth the total flux of fast neutrons; inside the building the measured flux is estimated to be one-third the total.

TABLE 5.5 PRESSURE VALUES FOR SHOCK-TUBE TESTS

p Overpressure (psi)	q Dynamic Pressure (psi)
10	2.2
20	3.1
30	16.9
35	22.0

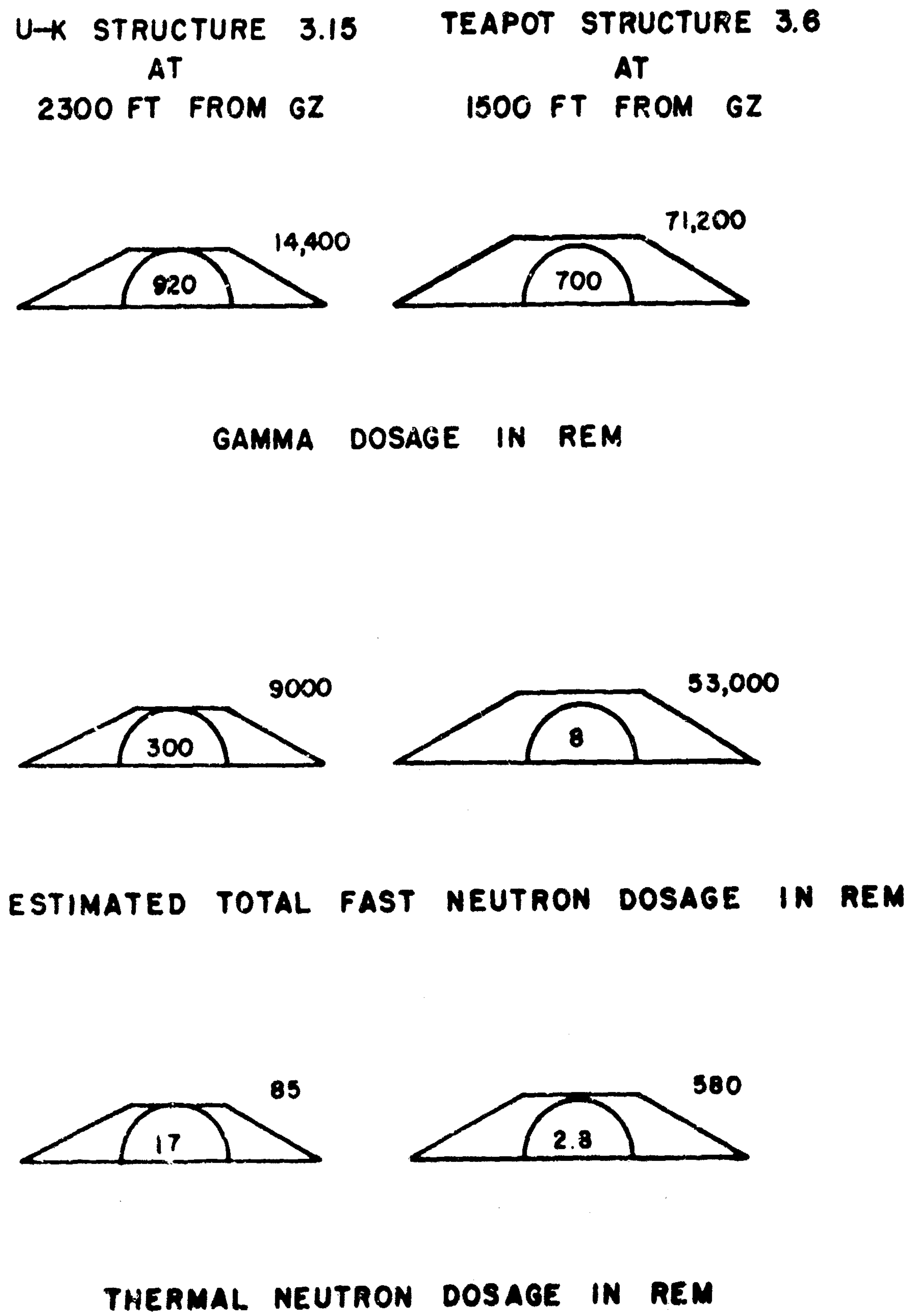


Figure 5.4 Estimated radiation dosage at Buildings U-K 3.15 and TEAPOT 3.6 on TEAPOT Shot 12.

pressures rather than the ratio, resulted in the list of equations below.

Gage Position	Equation
1	p gage = 1.00 p + 0.72 q
2	p gage = 0.85 p + 0.66 q
3	p gage = 0.76 p + 0.54 q
4	p gage = 0.83 p - 0.60 q
5, 6, 7,	p gage = 1.00 p - 0.60 q
8	p gage = 1.07 p - 0.58 q
9	p gage = 1.00 p - 0.41 q

Where: p gage = pressure against the earth berm
p = side-on pressure on the blast line
q = dynamic pressure on the blast line

The shock-tube data cover a range of q/p between 0.2 and 0.7. The extent of the extrapolations of field conditions required extrapolation to corresponding values of between 3 and 10.

Comparison of the actual pressures against the earth berm with those predicted by the shock-tube experiments over this tremendous extrapolation makes it clear that such shock-tube measurements are not of significant value in assisting in the prediction of field results. This is not surprising in view of the gross extrapolation. It suggests that if shock-tube measurements can be pushed to shocks of very much greater strength, the possibility of their use for prediction purposes will be improved. Even the fact that the ratio of q to p found in the field differs so greatly from the ideal values found in the shock tube may well mean that shock-tube data, even under high shock strengths, can be used only for gross approximations.

Chapter 6
CONCLUSIONS

6.1 TEAPOT SHOT 12

The conclusions which are based on this test and which involve its results, without regard to previous test results or considerations outside the test, are as follows:

1. The structure and configuration tested (Building 3.6) would serve as an adequate shelter under conditions in the open not exceeding any of the following conditions:

Average side-on pressure	30 psi
Average dynamic pressure	80 psi
Total flux prompt radiation	10,000 r

Actually, the structure would probably withstand a still larger side-on pressure if the coincidental dynamic pressure were sufficiently small. In regard to pressure, it is believed that the average value during the first 100 or 200 msec is of greater significance than the peak value.

2. The capabilities of this specific configuration have been adequately bracketed and no further field tests of it are warranted.

3. Models appear useful and a laboratory model test program should be undertaken prior to any full-scale field test of earth-covered shelters.

6.2 SHELTERS IN GENERAL

If consideration is given to results of other tests and to items of general knowledge outside the scope of the TEAPOT test, the following conclusions can be reached in regard to shelters in general. Some of these conclusions basically represent the author's opinion and may not be subject to clear proof.

The general context for these conclusions is that large-yield weapons are of greater significance than small-yield weapons and that large-yield weapons will be detonated at low scaled heights of burst. In such situations the area covered by fallout of dangerous levels is very much

larger than the area within which ordinary construction will be damaged by blast.

1. The designer of a personnel shelter should, for most situations, aim his design primarily toward protection against radiation from fallout and only secondarily to its protection against the blast forces. Out of a thousand surface or partially buried shelters in the vicinity of atomic explosions it should be expected that a far greater number will prove to have protected occupants against danger from fallout radiation than will prove to have protected occupants from blast damage. (There are situations of great military importance where the criterion for shelter should be primarily protection against blast rather than against radiation. In general, such shelters should be deeply buried and their cost will be much greater than that for surface or partially buried shelters. It is believed that deep shelters probably constitute only a small fraction of the total number of shelters which should be built to protect military personnel.)

2. Radiation protection depends primarily on the thickness of the earth cover at the spots where the thickness is least

3. Blast protection of aboveground shelters depends primarily on their resistance to wind rather than to overpressure (to q rather than to p).

4. To obtain maximum blast protection with a given minimum thickness of earth cover, the shelter should be completely buried.

5. To obtain maximum blast protection with a given thickness of earth cover and at a minimum cost, the shelter should be partially buried so that the volume of the cut approximates the volume of the fill.

6. To obtain maximum blast protection at minimum cost, the span of the arch should be minimum. Length has no influence.

7. The high-rise arch appears superior to any alternative shape to carry the necessary load of earth cover and afford a further margin against blast loads.

8. The design and material of a high-rise arch should be of types which permit considerable deflection beyond the elastic range before its resistance decreases. The relative merit of corrugated steel compared to under-reinforced concrete or wood with plastic steel hinges is not currently determined.

9. Stabilization or other strengthening of the fill material should be given careful consideration. It is possible that such procedures would result in enhancement of strength at low cost and hence would represent an approach to the most economical design.

10. Static tests of models will be valuable in approaching an optimum design of shelters at a minimum of cost.

11. The configuration tested on TEAPOT shows sufficient promise to warrant a program of shelter design based on the earth-covered, high-rise steel arch. Such design should include multiple entrances, complete with necessary baffling, ventilation, and other services, the storage of food and medical supplies, and the like. It is believed that a partially buried structure consisting of three steel arches of 8-foot span, placed side by side, is a closer approach to optimum design. The arches would be supported on low concrete or masonry walls carried up above the subgrade floor of the structure to a height sufficient to give adequate

head room. Earth cover above the crown of the arch would be 4 feet and the flat top of the earth cover would be carried to a distance away from the side of the outer arches at least twice the height of the earth cover above original ground level.

12. The design of earth-covered shelters based on stress analysis is not possible under present conditions and further effort in this direction is not advisable. The precise loads to which a shelter may be subjected are not well known and probably cannot be established; similarly, the mechanism by which earth cover transmits such loads is not well established and the characteristics of fill materials which determine these mechanisms are not well known.

REFERENCES

1. R. B. Vaile, Jr., The Effects of ˉ rth Cover in Protecting Structures Against Blast, AFSWP-357, St ord Research Institute, 30 September 1954. CONFIDENTIAL RESTRICTED DATA

2. Letter from U. S. Naval Civil Engineering Research and Evaluation Laboratory, Serial 2726, Reference No. NT4-59/NY 340 030 783/CRW/jdr, April 1, 1955. UNCLASSIFIED.

3. J. R. Allgood, C. K. Wiehle, and W. A. Shaw, Static and Dynamic Studies of Three Personnel Shelters: Armco II, Structure 3.15, Structure 3.13a, Technical Note N-159, U. S. Naval Civil Engineering Research and Evaluation Laboratory, 29 June 1953. SECRET

4. D. C. Sachs, Air Blast Overpressure and Dynamic Pressure Over Various Surfaces, WT-1109, Operation TEAPOT Project 1.10, Stanford Research Institute, to be published. SECRET RESTRICTED DATA

5. H. K. Gilbert and E. B. Doll, Summary Report of the Technical Director, Programs 1-9, WT-1153, Operation TEAPOT, Armed Forces Special Weapons Project, to be published. SECRET RESTRICTED DATA

6. John R. Hendrickson et al., Shielding Studies, Draft of WT-1121 (presumably), Operation TEAPOT Project 2.7, Chemical Corps, Chemical and Radiological Laboratories, 21 October 1955. SECRET RESTRICTED DATA

7. R. M. Longmire, LTJG, and L. D. Mills, LTJG, Navy Structures, WT-729, Operation UPSHOT-KNOTHOLE Projects 3.11-3.16, Bureau of Yards and Docks, May 1955. CONFIDENTIAL RESTRICTED DATA

8. CDR Arthur B. Chilton, The Biological Hazards of Neutrons, Bureau of Yards and Docks, August 1954. OFFICIAL USE ONLY

9. Recommendations of the International Commission on Radiological Protection, British Journal of Radiology, Supplement No. 6, 1955. UNCLASSIFIED

10. P. S. Harris et al., Physical Measurement of Neutron and Gamma Radiation Dose from High Neutron Yield Weapons and Correlation of Dose with Biological Effect, Operation TEAPOT Project 39.7, WT-1167, to be published. SECRET RESTRICTED DATA